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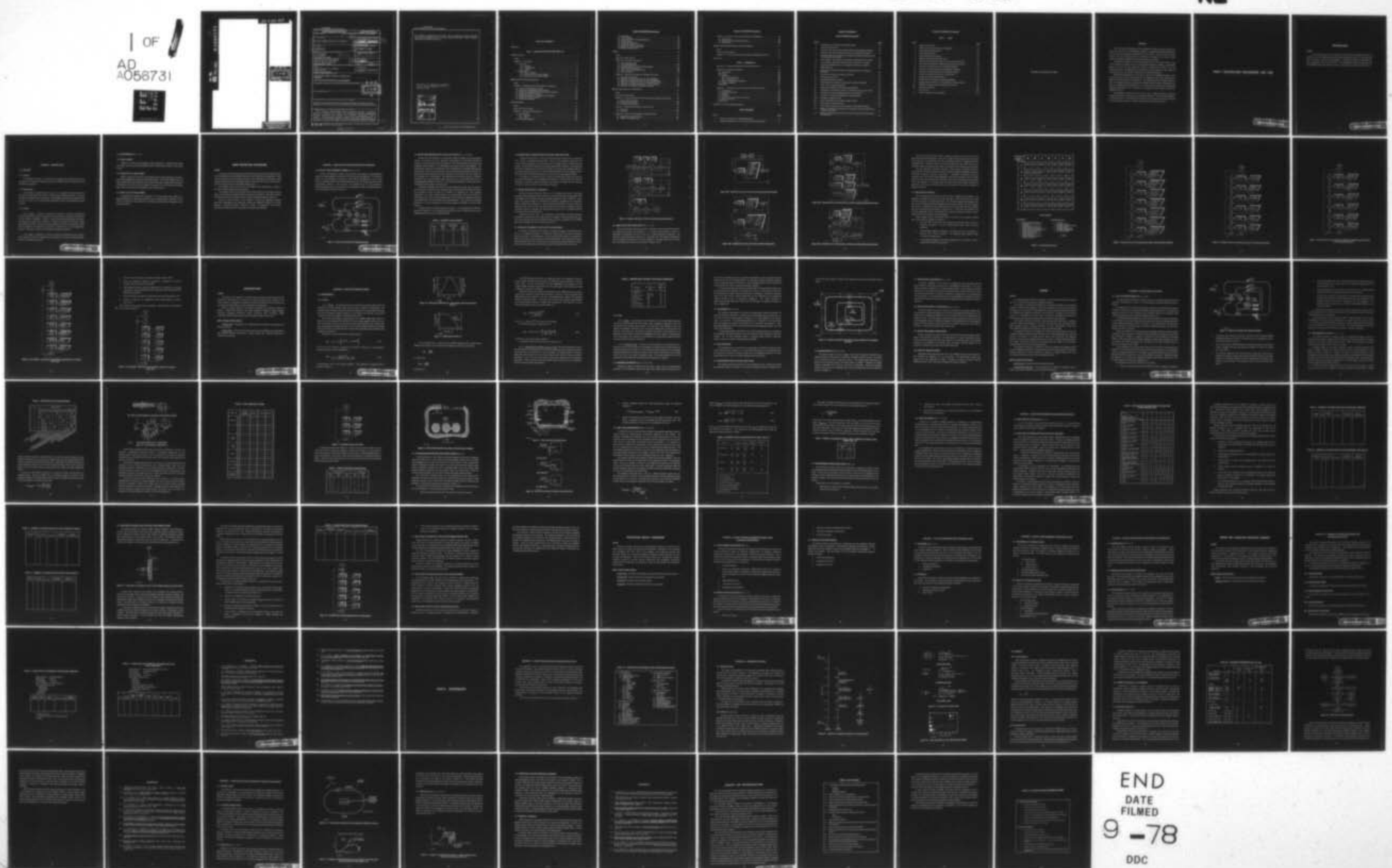

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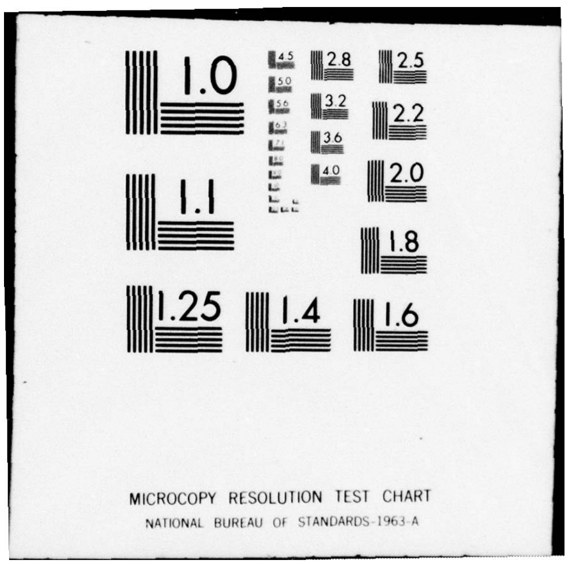
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The Prototype HEMP Design Practice Handbook provides a systematic approach to protection of the DCS. The handbook is based on a generalized protection procedure which parallels the programed development cycle of systems. This protection procedure employs the zonal characterization of facilities and utilizes nested shields, regional grounding, penetration and aperture treatments in the form of design practices as the primary protection measure. over

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PREFACE

The Prototype HEMP Design Practice Handbook provides a systematic approach to protection of the DCS. The handbook is based on a generalized protection procedure which parallels the programed development cycle of systems. This protection procedure employs the zonal characterization of facilities and equipment and utilizes nested shields and regional grounding as the primary protection measure.

The handbook employs a do-it-yourself approach and is structured so that a minimum of analysis is required of users in solving DCS protection problems. Considerable tabular and graphical data along with realistic examples are included to aid the protection process. An appendix of the handbook acts as a repository of the design and validation practices which are key elements in the protection process.

Shielding and grounding were selected as the bases of HEMP protection as they provide the most realistic and general way of dealing with the direct penetration of HEMP fields into facilities and equipment. The shields provide an excellent reference point for treating penetrating conductors for HEMP induced currents. Protection by an effective shielding and grounding scheme is a well known and consistantly recommended protection method (Ref. 1-4). Moreover it is compatable with protection for RFI and TEMPEST (Ref. 2).

The handbook is separated into two parts. Part 1 contains introductory material, the protection procedure and use of the procedure elements. Part 2 contains appendices of detailed resources. The handbook is structured in this manner to avoid user confusion by restricting the exposure to in-depth material unless required by the user.

PART 1 PROTECTION PROCEDURE AND USE

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INTRODUCTION

SCOPE

This introduction series is to acquaint the users with the handbook, as well as to inform them of the HEMP problem and present reasonable solutions. The introduction has two sections: Overview and Background. The Overview covers the handbook purpose, organization and content summary. The Background briefly acquaints the user with HEMP phenomology, the affect it has on communications and how to deal with it.

CHAPTER 1 - INTRODUCTION

1.1 OVERVIEW

1.1.1 Purpose

The handbook's purpose is to provide various engineering personnel levels with a procedure for achieving a balanced allocation of HEMP protection measures for DCS facilities and equipment.

1.1.2 Organization

The handbook is organized into two parts. Part 1 presents the procedures for the specification, allocation, and selection of design and validation practices. This part contains ten chapters under six headings. Each heading is printed on an extended tab as an aid to the user. Part 2 contains three appendices which provide detailed resource material.

1.1.3 Content

1.1.3.1 Part 1. Chapter 1 introduces the handbook. Chapter 2 discusses the characterization of facilities and equipment, the elements of the protection procedure, the user matrix and examples. Chapter 3 covers protection specifications, and protection allocation is presented in Chapter 4. Chapter 5 discusses the selection of design and validation practices. Protection quality assurance practices for production, installation, acceptance, and operation are covered in Chapters 6, 7, 8, and 9 respectively. Chapter 10 contains a summary of the design and validation practices.

1.1.3.2 Part 2. Appendix A contains the design and validation practices. Equipment response is covered in Appendix B, and Appendix C discusses coupling and penetrations into shielded enclosures.

1.2 BACKGROUND (Ref. 1, 4, 5)

1.2.1 What is HEMP?

HEMP is an intense electromagnetic pulse produced by a high-altitude nuclear burst which reaches a peak field strength of tens of kilovolts per meter in a few nanoseconds.

1.2.2 Why Do We Care About HEMP?

HEMP is significant because a single high-altitude nuclear detonation can illuminate large geographical areas with this pulsed energy. The incident HEMP field can induce large currents and voltages on the exterior and interior cables and structures of communication facilities, which, if allowed to couple to the circuit level, can produce upset of the circuit function and damage to the component parts.

1.2.3 What Can You Do About HEMP?

Communication facilities and equipment can be protected from HEMP by a balanced allocation of protection practices such as layered shields, treatment of the cables and structures that penetrate the shields, and utilization of equipment with intrinsic protection.

HEMP PROTECTION PROCEDURE

SCOPE

The user protection procedure and protection matrix comprise the systematic plan of the handbook for providing HEMP protection of DCS facilities and equipment. These tools are structured so as to provide protection that is balanced and cost effective, deal with all issues required for protection, address a wide spectrum of users, and provide a protection solution from any reasonable starting point.

This segment acts as the key for the handbook user, allowing him to obtain a solution for his particular protection problem.

The segment consist of one chapter where initial sections of the chapter informs users of the elements contained within the protection procedure. The latter sections present the protection procedure and user matrix along with examples of their use.

There are seven sections in the Chapter: Facility and Equipment Zoning, Protection Methodology and Allocation, Design and Validation Practices and Their Selection, Protection Quality Assurance, Phases of Equipment and Facility Development, HEMP Protection Procedure, and Protection Examples.

CHAPTER 2 - HEMP PROTECTION PROCEDURE WITH EXAMPLES

2.1 FACILITY AND EQUIPMENT ZONING (Ref. 3, 4, 6, 7)

Facility and equipment zoning is the process of identifying or creating different regions of electromagnetic environment within facilities and equipment. The different regimes of electromagnetic environments arise with the introduction of one or more layers of shielding between the external environment and the small-signal environment of equipment interiors. Thus, facilities and equipment may be characterized by different equipotential zones isolated by electromagnetic barriers or shields (referred to as zone boundaries and shown in Figure 1).

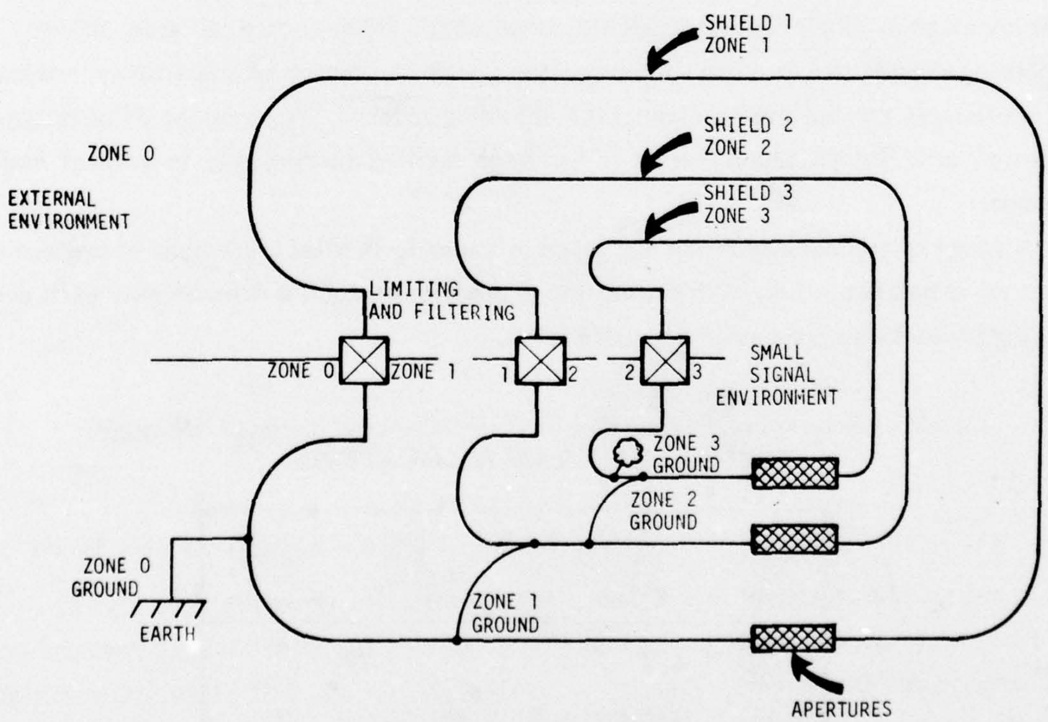

Figure 1. Nested zone shields with regional grounding

2.2 PROTECTION METHODOLOGY AND ALLOCATION (Ref. 1, 3, 4, 8, 9)

Ideally, the zone boundaries are continuous, closed, and highly conducting Faraday shields. In practice, they are generally compromised by penetrating conductors (referred to as zone penetrations) and apertures. The zonal description of facilities and equipment leads naturally to the methodology of protection used in the handbook. This methodology is based on the requirement that an adequate level of HEMP shielding must exist between the exterior environment and the small-signal environment and that all apertures and zone penetrations must be treated in such a manner that the integrity of the shielding is not compromised. This philosophy was selected because, in general, protective devices and techniques alone cannot protect a total naked system (i.e. no shielding) against HEMP at finite cost. This protection philosophy is well known and is consistantly recommended in the literature.

Protection allocation is the process of distributing the overall protection requirements between the different zone shielding layers and intrinsic zone protection levels. The allocation process provides the flexibility of assigning the total shielding requirement to a single envelope shield or to small-volume critical area shields, or distributing it over two or more shielding layers, with the option of substituting intrinsic zone protection for the most nested zone shielding layers. The concept of distributed protection is a proven technique as it has been applied successfully in several major programs.

A range of typical allocation are given in Table 1. A vital ingredient of protection allocation is balance - i.e., distributing the protection in such a manner that each area requiring protection receives an adequate level.

TABLE 1. RANGE OF ALLOCATIONS

Envelope S.E. (dB)	Cable Shielding S.E. (dB)	Small Volume Critical Area S.E. (dB)	Intrinsic Zone Protection
100	--	--	No
60	--	40	No
40	60	60	No
30	--	35	Yes
--	50	50	Yes
--	--	50	Yes
--	--	80	Yes

2.3 DESIGN AND VALIDATION PRACTICES AND THEIR SELECTION

A design practice (Ref. 3, 10) is a protection measure that provides a protection level ≥10 dB. A validation practice (Ref. 1, 10) is a test or analysis method that will verify with high confidence the protection level of a design practice. Design practices include such protection measures as shielding, penetration treatments, and grounding. Protection validation practices include inspection, injection tests, shielding effectiveness tests, and protection analysis. Only through employment of a self-consistent set of design practices in facilities and equipment can they be protected against HEMP.

The selection of design practices is based on the specified protection allocation, protection effectiveness, cost, feasibility, and reliability. Factors which enter into the selection of protection validation practices are the type of design practice requiring verification, cost, and the level of verification required.

2.4 PROTECTION QUALITY ASSURANCE

Protection Quality Assurance (Ref. 3, 11-13) includes the control, monitoring, evaluation, and maintenance efforts carried out to provide facilities and equipment with the designed level of HEMP protection throughout production and its useful life. These efforts take place during the development, production, installation, and acceptance phases of facilities and equipment. They include the development of various protection assurance plans which set forth the special procedures for review, inspection, testing, screening, personnel training, and documentation required for the HEMP-protected articles during the particular phase.

Additional activities are: the preparation of procedures covering operation, surveillance, maintenance, and modifications and changes. These procedures set forth the actions required during the operational phase to assure an adequate level of HEMP protection throughout the facility and equipment life.

2.5 PHASES OF EQUIPMENT AND FACILITY DEVELOPMENT

Facilities and equipment are brought into existence through an evolutionary cycle which is a programed sequence of operations interspersed with various milestone reviews and tests. This development cycle contains several phases, as presented in Figure 2, running from the concept to the operational phase. The protection procedure, (to be discussed next), which complements this evolutionary sequence, begins to interact during the specification phase and continues until the operation phase commences.

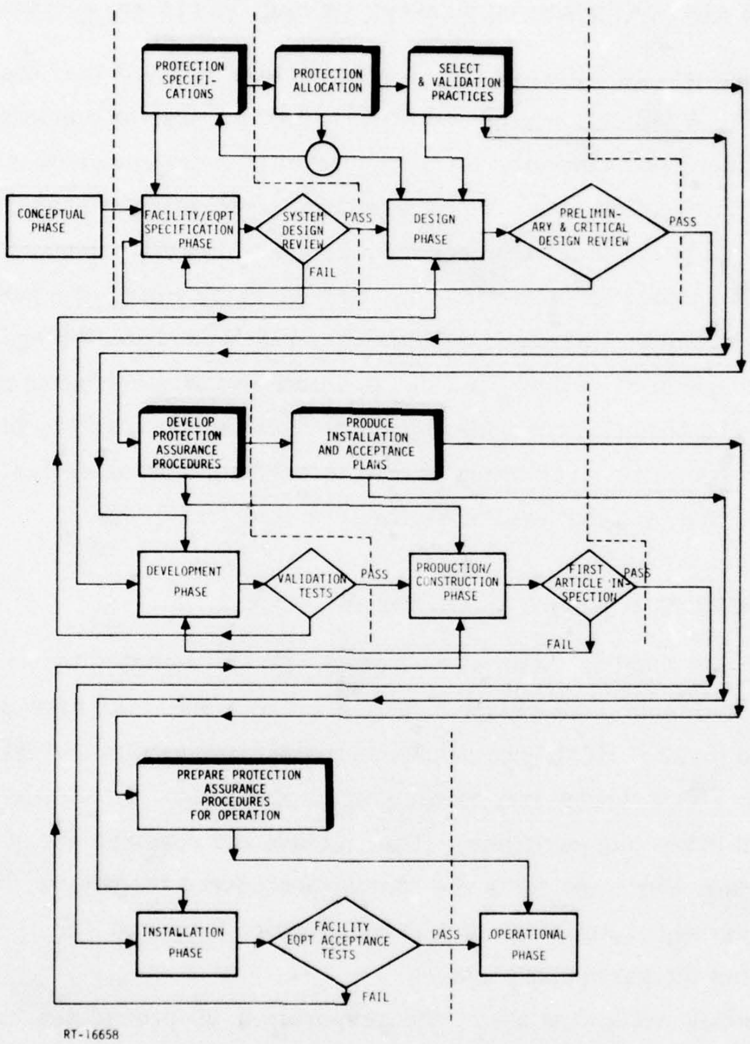

Figure 2. Program development flow with protection procedure inputs

2.6 HEMP PROTECTION PROCEDURE (Ref. 1, 3, 12)

The user protection procedure provides a systematic means of solving the protection problem for facilities and equipment. It is a generalized procedure, in that it is applicable to protecting an entire facility or a single equipment component. The structure of the procedure parallels and is compatible with the program development flow of facilities and equipment as shown in Figure 2. Detailed charts, each covering one or two phases of the protection, are given in Figure 3 (a-d).

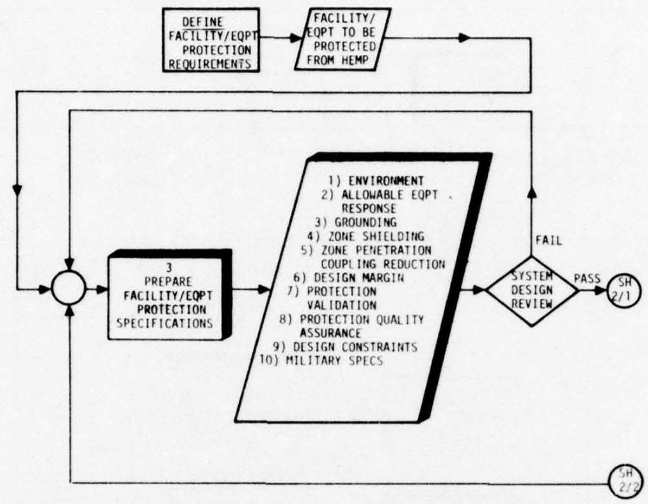

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Figure 3(a). Detailed chart of the protection procedure specification phase

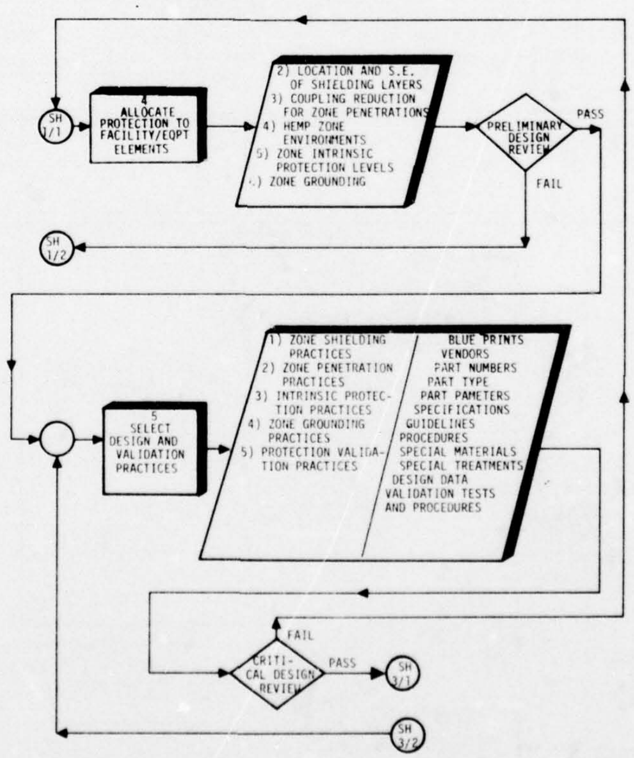

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Figure 3(b). Detailed chart of the protection procedure design phase

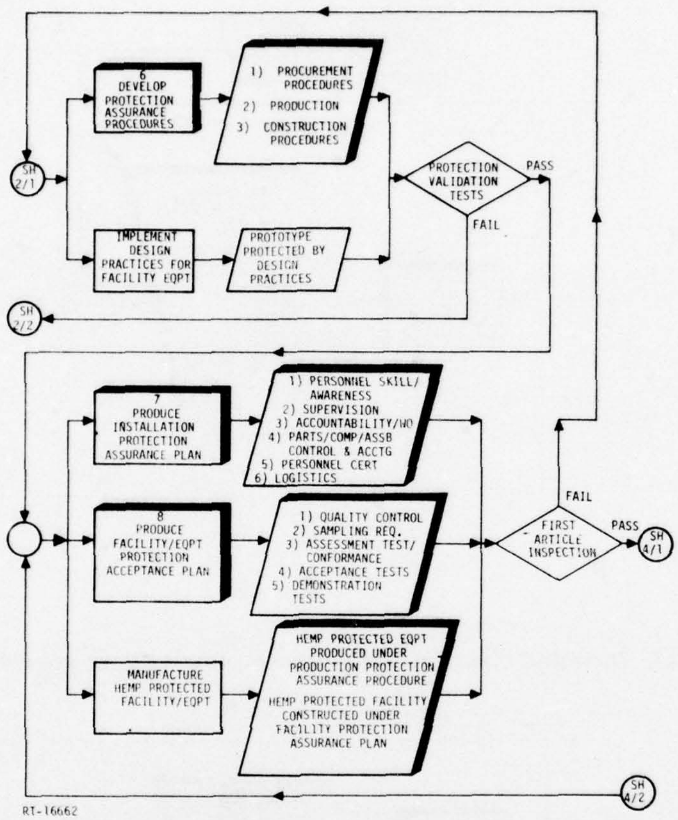

Figure 3(c). Detailed chart of the protection procedure development/production phase

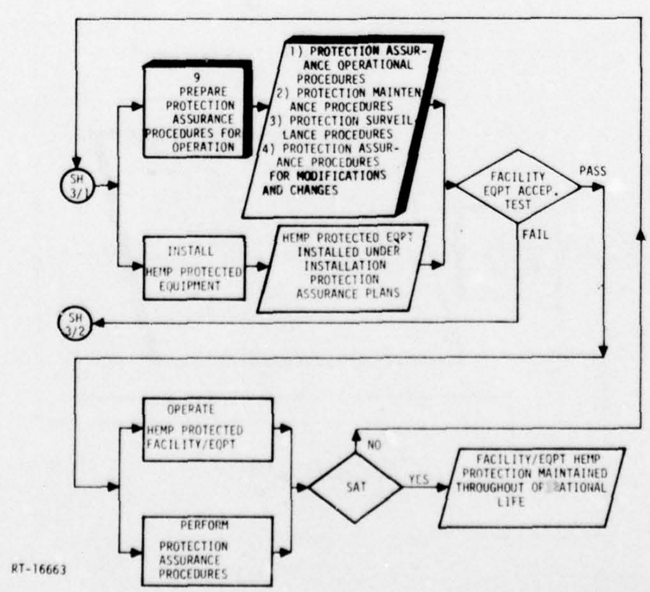

Figure 3(d). Detailed chart of the protection procedures installation/acceptance phase

The user protection matrix given in Figure 4 provides for user entry into the generalized protection procedure. The matrix is based on the categorization of the user by his function, F, and function level, FL, as defined in Figure 4. Employing the F/FL designation for a particular user in the matrix provides the user with the pertinent handbook chapter and sections which allow him to perform his required protection task.

The user protection procedure consists of seven steps: (1) prepare protection specifications, (2) allocate protection levels, (3) select design and validation practices, (4) develop protection assurance procedures, (5) produce installation protection assurance plan, (6) produce facility/equipment protection acceptance, and (7) prepare protection assurance procedures for operation. Each step in the procedure is associated with a user function. A summary chart for three of the seven steps depicting the protection task for each function level and the results of that task is provided in Figures 5 through 7.

2.7 PROTECTION EXAMPLES

Seven examples will be given to aid the users in applying this handbook. One example is provided for each of the user functions, with the function level being selected to provide a representative sample. For instance, consider the example of the user who must specify protection requirements for an entire facility. His F/FL designation is A/1. Consulting the user protection matrix, the user finds that his protection task will be performed using Chapter 3, Sections 1-10. A flowchart which depicts how this user progresses through the specification protection procedure element, and the specification which result are shown in Figure 8.

After passing through two decision blocks, he arrives at the procedure starting point, which tells him to begin in Chapter 3.

1. The first item to specify is the external environment, which is found in Section 1 and gives: 50 kV/m incident plane wave with worst-case incidence.

2. The allowable equipment response is specified next and is considered in Section 2 from which is obtained: no component part damage, upset $\leq$ 10 msec, no manual reset.

3. The grounding philosophy is specified using Section 3, which gives: exterior ring ground and regional zone ground.

FUNCTION → / FUNCTION LEVEL ↓	A	B	C	D	E	F	G
1	CHAP. 3 Sect. 1-10	CHAP. 4 Sect. 1-6	CHAP. 5 Sect. 1-6	CHAP. 6 Sect. 1-3	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
2	CHAP. 3 Sect. 1, 3 through 10	CHAP. 4 Sect. 1-3, through 6	CHAP. 5 Sect. 1-3, 5-6	CHAP. 6 Sect. 1-2	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
3	CHAP. 3 Sect. 1-10	CHAP. 4 Sect. 1-3, 6	CHAP. 5 Sect. 1-3, 5-6	CHAP. 6 Sect. 3	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
4	CHAP. 3 Sect. 2-10	CHAP. 4 Sect. 1-4, 6	CHAP. 5 Sect. 1-3, 5-6	CHAP. 6 Sect. 1-2	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
5	CHAP. 3 Sect. 2-10	CHAP. 4 Sect. 1-6	CHAP. 5 Sect. 1-6	CHAP. 6 Sect. 1-2	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
6	CHAP. 3 Sect. 2-10	CHAP. 4 Sect. 1-6	CHAP. 5 Sect. 1-6	CHAP. 6 Sect. 1-2	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4
7	CHAP. 3 Sect. 1-10	CHAP. 4 Sect. 1-6	CHAP. 5 Sect. 1-6	CHAP. 6 Sect. 1-2	CHAP. 7 Sect. 1-6	CHAP. 8 Sect. 1-5	CHAP. 9 Sect. 1-4

USER CATEGORIES

FUNCTION (F):

A. SPECIFY PROTECTION REQ.
B. DETERMINE WHAT AND WHERE TO PROTECT
C. DETERMINE HOW TO PROTECT
D. ASSURE PROTECTION QUALITY DURING PRODUCTION/CONSTRUCTION
E. ASSURE PROTECTION QUALITY DURING INSTALLATION
F. VERIFY PROTECTION QUALITY FOR ACCEPTANCE
G. ASSURE PROTECTION QUALITY DURING OPERATION

FUNCTION LEVEL (FL):

1. FACILITY
2. EXTERIOR CABLES
3. BUILDING AND PENETRATIONS
4. INTERIOR CABLES
5. EQUIPMENT ENCLOSURES
6. EQUIPMENT COMPONENTS
7. SYSTEM EQUIPMENT

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Figure 4. User protection matrix

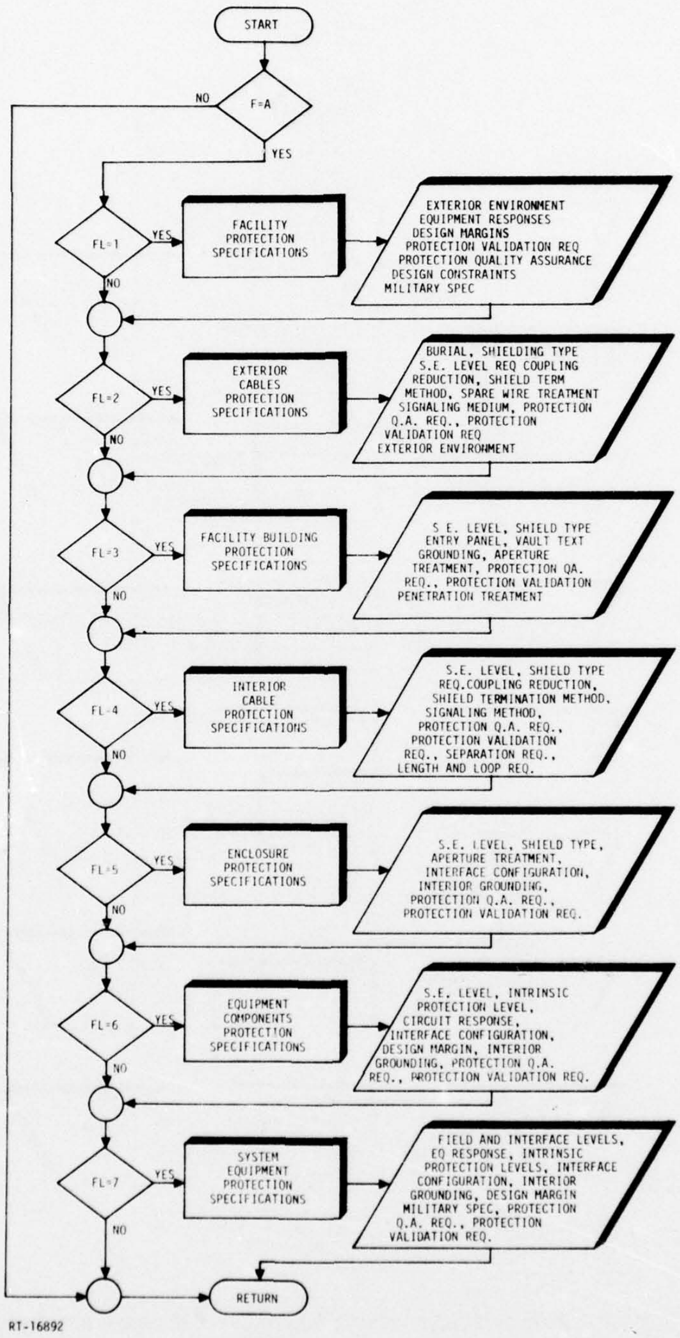

Figure 5. Summary chart for the specification step in the protection procedure

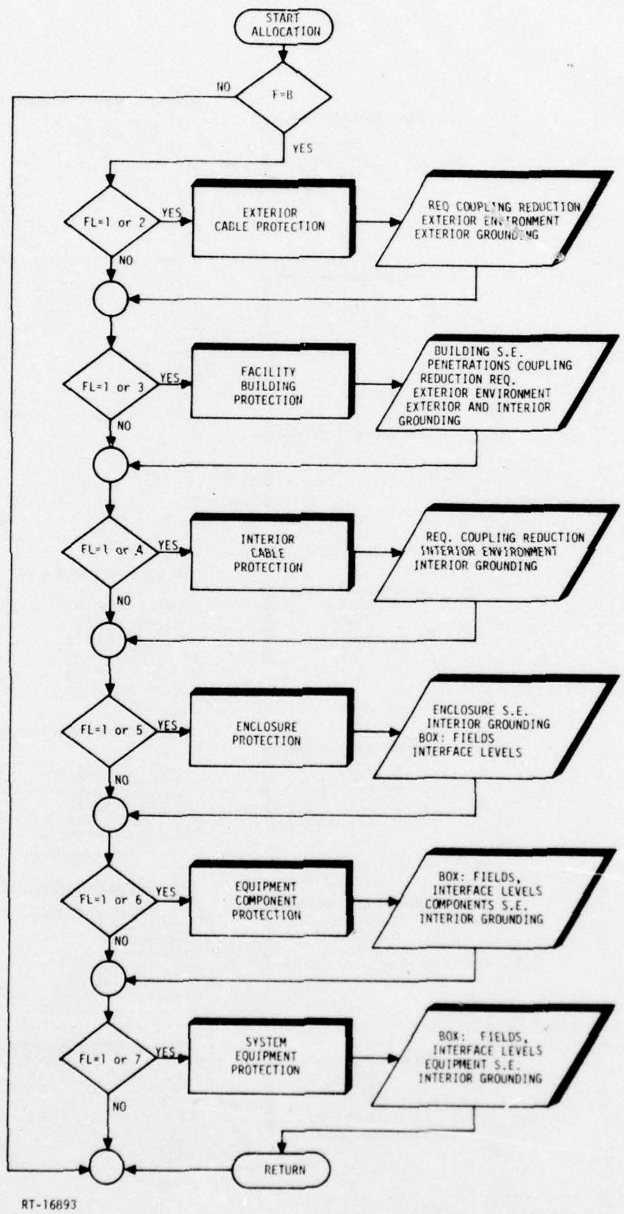

Figure 6. Summary chart for the allocation step in the protection procedure

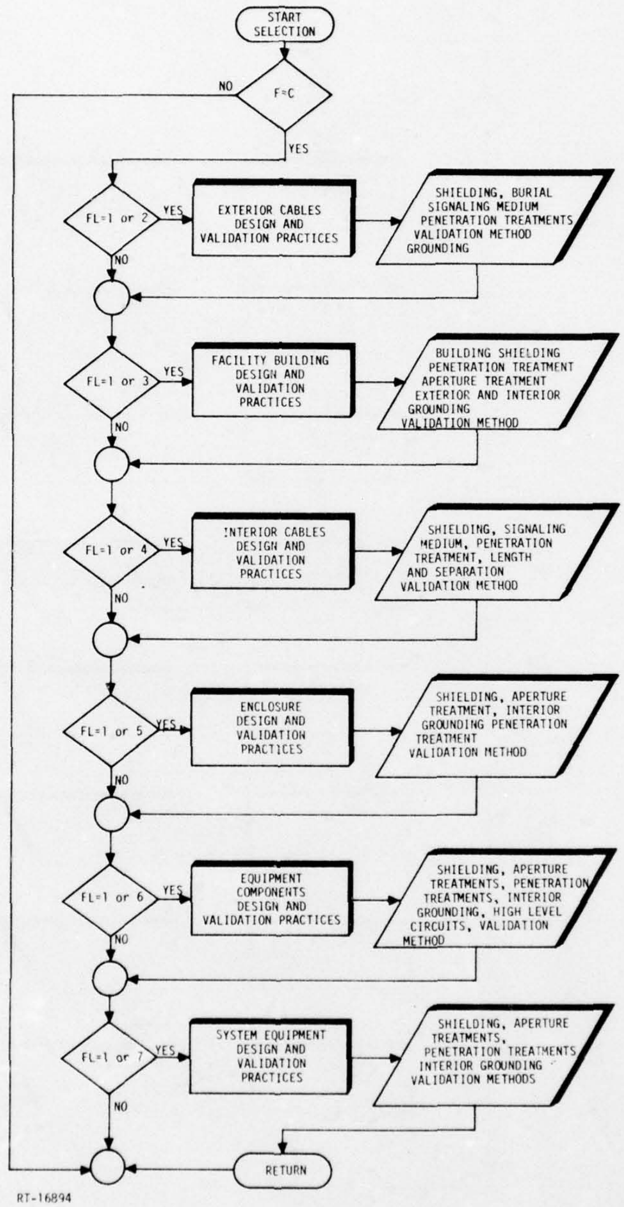

Figure 7. Summary chart for the selection of design and validation practices step in the protection procedure

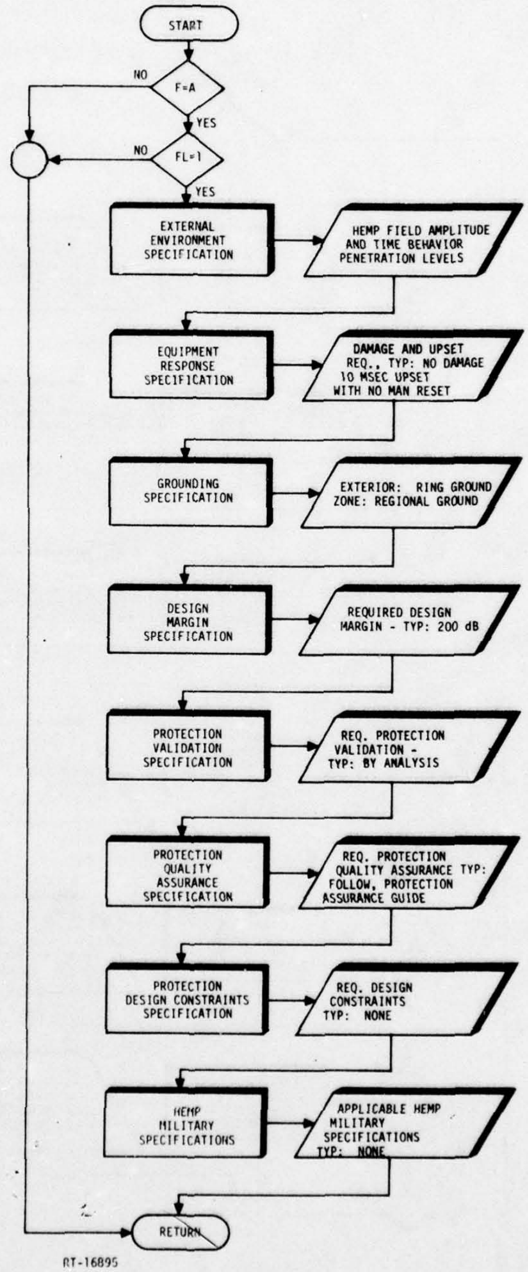

Figure 8. User example - specification of protection requirement for a facility (F/FL=A/1)

4. Section 6 is used to specify the protection design margin: 20 dB.

5. Next, the protection validation requirement is specified in Section 7, yielding: validation required by analysis.

6. The protection quality assurance requirements are specified in Section 8, which gives: follow Protection Quality Assurance Guide for Systems With Moderate Requirement.

7. Protection design constraints are specified in Section 9 which gives: none.

8. Section 10, specifies the applicable military specifications for protection: none.

This completes the procedure and the example. A flow chart for a user example F/FL = B/1 is given in Figure 9.

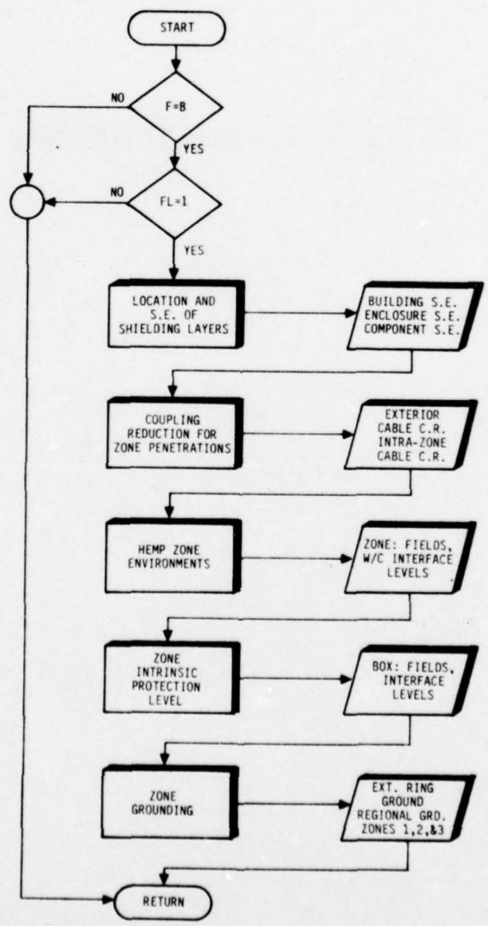

Figure 9. User example - determine what and where to protect in a facility (F/FL=B/1)

SPECIFICATIONS

SCOPE

The thrust of this segment is to inform the user about protection specifications. Basically, it tells the user the information he needs to specify, how to specify it, and when to specify. Additionally it provides a suitable data base so that he can select the actual data or information he needs in preparing the specification.

There is a single chapter in this segment comprised of ten different sections as follows: Environments (exterior and zone), Equipment Response, Design Margins, Protection Validation, Protection Quality Assurance, Zone Grounding, Design Constraints, Military Specifications, Zone Shielding, and Zone Penetrations.

INPUTS FROM OTHER PHASES

Concept Phase: Requirement for HEMP protected facilities and equipment and design constraints.

Design Phase: Zone field and interface levels, zone shielding, and zone penetration coupling reduction requirements. Specific design and validation practices for facilities and equipment.

CHAPTER 3 - PROTECTION SPECIFICATIONS

3.1 ENVIRONMENTS

3.1.1 Exterior

3.1.1.1 Fields. The specifications of the exterior environment should cover the characteristics of the incident fields, as well as other important considerations. The quantities which should be specified include the following: wave type; peak field value; the time-and-frequency domain behavior of the fields, which provides rise and fall times; pulse width and frequency content; and polarization.

The exterior environment is determined by the incident HEMP field, which is a plane wave with a peak electric field of 50 kV/m and a peak magnetic field of 133 A/m. The total exterior fields at any point also include the reflection of the incident field from ground planes and nearby structures. Thus, the total exterior fields at a particular point can be larger or smaller than the incident fields, depending on the different field component contributions.

The behavior of the incident electric field is given by

$$E(t) = 5.25 \times 10^4 \left[e^{-4 \times 10^6 t} - e^{-4.76 \times 10^8 t} \right] \tag{3.1}$$

in V/m, and t is in seconds. Equation (3.1) is plotted in Figure 10. In the frequency domain, the electric field is expressed as

$$E(\omega) = \frac{2.47 \times 10^{13}}{(j\omega + 4 \times 10^6)(j\omega + 4.76 \times 10^8)} \tag{3.2}$$

in volts-sec/m, and ω is the radian frequency. The magnitude of Equation (3.2) is plotted in Figure 11.

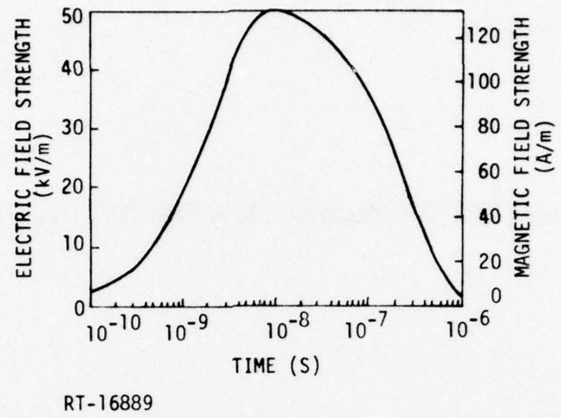

Figure 10. Generalized HEMP electric- and magnetic-field time waveform (Ref. 5)

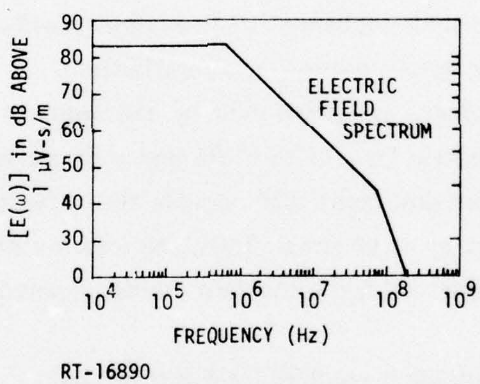

Figure 11. HEMP spectrum (Ref. 5)

As the incident field is a plane wave, the HEMP magnetic field is related to the HEMP electric field by the characteristics impedance of free space, as follows:

$$H(t) = \frac{E(t)}{377\Omega}$$

in amp/m, and

$$H(\omega) = \frac{E(\omega)}{377\,\Omega}$$

in amp-sec/m.

The HEMP polarization, which is a significant factor in its coupling to communication centers, depends on several factors, including the local orientation to the geometric field. To yield results which are site independent, the polarization of the incident HEMP waveform is specified to be that polarization which yields worst-case coupling for the problem of interest.

Equation (3.1) gives an adequate representation of the HEMP field for most applications (e.g., frequencies content below 100 MHz). However, it does overestimate the high-frequency pulse content in the case of antenna/receiver systems with operating frequencies above 100 MHz. A waveform which gives a more realistic approximation for the high-frequency behavior of HEMP must be specified. This waveform is a modified double expotential and is expressed as (Ref. 14)

$$E(t) = \frac{55.05 \times 10^{3} e^{2 \times 10^{8} \tau}}{1 + e^{2.04 \times 10^{8} \tau}} \tag{3.3}$$

in V/m, $\tau = t - 3.83 \times 10^{-10}$, and τ and t are in seconds.

The Fourier transform of Equation (3.3) is

$$E(\omega) = 8.48 \times 10^{-3} \sin^{-1} \left[\frac{\pi (2 \times 10^{8} - j\omega)}{2.04 \times 10^{8}} \right] \tag{3.4}$$

in volt-sec/m, and ω is the radian frequency.

An additional reference for this section is Reference 15.

3.1.1.2 Penetration Levels (Ref. 15, 16, 17, 18). The exterior penetration levels are determined by the interaction of the incident HEMP field with external structures and conductors that penetrate the zone 0/1 shield. The specifications for exterior penetration levels should cover worst-case induced bulk currents in amps and source impedance in ohms for the common types of penetration expected for the particular application. Table 2 gives the worst-case induced bulk currents and source impedances for some common types of penetrations.

TABLE 2. PENETRATION CURRENTS AND SOURCE IMPEDANCE

Penetration Type	I_p W/C Bulk Current (amp)	Source Impedance (Ω)
Buried/Surface Cable	450-1435	100
Overhead Cable	4000-10000	500
Waveguides	3000	75
Local Telephone	5000	100
Exhaust	900	50
Buried Waterline	1500	100
A/C Coolant Line	300	50

3.1.2 Zone

3.1.2.1 Fields. Zone fields arise from diffusion of the incident HEMP waveform through the shield boundaries which usually causes a significant alteration in both the peak field levels and their time histories. The quantities to be specified are the zone electric and magnetic field levels in V/m and amp/m, respectively, as well as their time behavior. For almost any metal shield boundaries, the electric field attenuation is so high that the zone electric field will be negligible and, hence, require no specification. The actual value of zone field and its time behavior to be specified is determined from the allocation process given in Chapter 4.

3.1.2.2 Interface Levels. Interface levels are produced at zone boundary interfaces (such as at an I/O interface of an equipment component) from currents induced on intrazone cables (which connect to the interfaces), by zone fields and by cross coupling. The interface levels are specified in terms of their Thevenin equivalent source (voltage source (V_S) with a series source impedance (R_S)). The actual interface levels to be specified are determined from the allocation process given in Chapter 4.

3.2 EQUIPMENT RESPONSE (Ref. 4, 5, 16, 19, 20)

Equipment response to HEMP takes two forms: upset, which is a nonpermanent alteration of the equipments operational state (may require manual intervention for

recovery), and damage, which is a permanent degradation of some equipment element (usually in one or more component parts). The equipment response should be specified as to the allowable upset in time (μsec to msec), including whether manual intervention can be utilized for recovery and that no damage is allowed.

The actual specified upset response is determined by the operational requirements of the system and its response time, among other factors. In some cases, no upset can be tolerated, and in others manual intervention is not allowable. Commonly, a specified upset of 10 msec with no manual intervention can be tolerated by most equipment without interfering with its operational capabilities. For further assistance in determining the specified upset criteria, see the discussion on equipment response in Part 2, Appendix B.

3.3 GROUNDING (Ref. 3, 4, 16)

The purpose of grounding is to provide an equipotential distribution between the dominant structural members of a system and the surrounding natural environment. In the case of zones, the surrounding environment is the zone shields; for the exterior case, it is the earth. The grounding specification is a statement of the particular ground philosophy that should be employed for the facilities and equipment. Most grounding philosophies that are currently used, such as the single-point ground, are valid only at low frequencies.

A ring ground should be specified for the exterior ground system, as it provides a low-impedance distributed ground system and minimizes earth gradients across the facility. For the zone grounding system, a regional ground should be specified. Figure 12 shows an example of this grounding philosophy.

3.4 ZONE SHIELDING

The shielding level of a particular zone boundary is determined during the allocation process given in Chapter 4. The zone shield whose level is to be specified could be a facility, an enclosure, a conduit, a cable tray, or an equipment enclosure. The zone shield is specified in terms of its dB of shielding effectiveness (S.E.).

3.5 ZONE PENETRATION COUPLING REDUCTION

The coupling reduction required for zone penetrations also is determined during the allocation process of Chapter 4. The required coupling reduction is specified to be

so many dB, which usually is equal to the required level of the zone shields S.E. plus 10 dB.

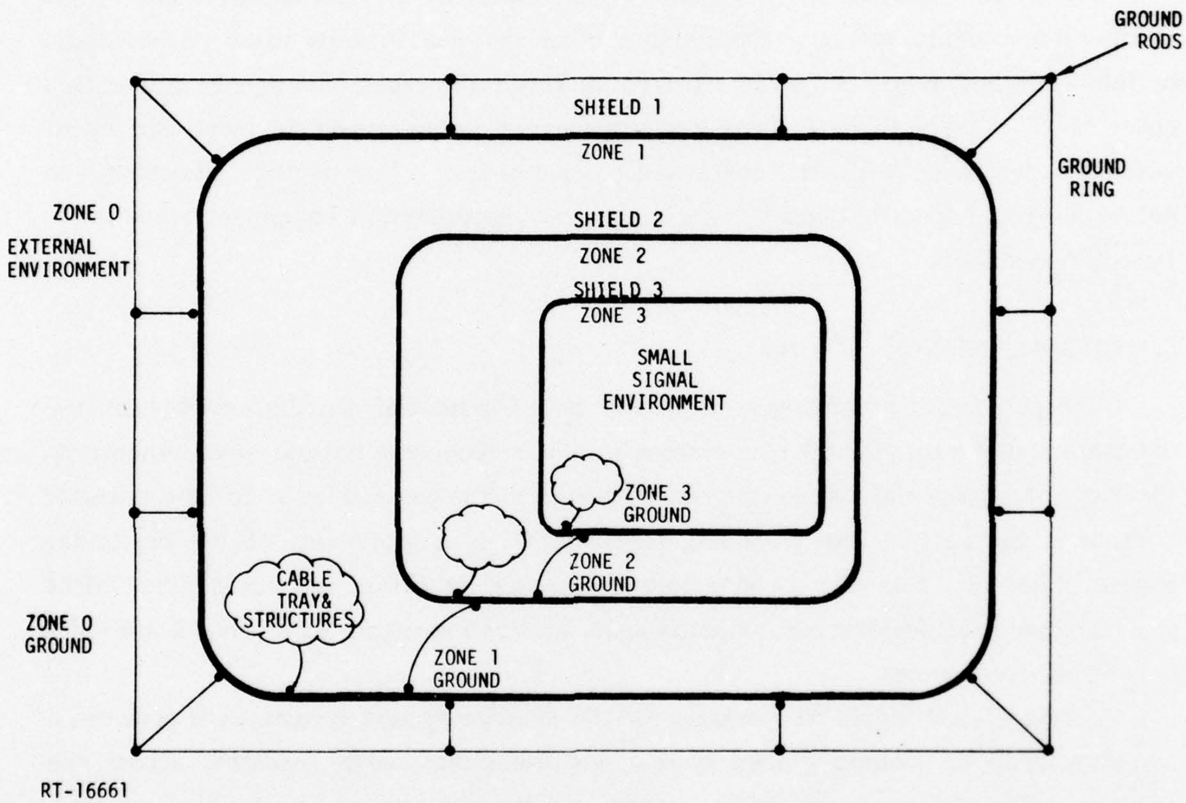

Figure 12. Nested zone shields with exterior ring grounding and zone regional grounding

3.6 DESIGN MARGIN (Ref. 20, 21, 22)

The design margin is the extra degree of protection that must be included in the design to allow for uncertainties in component thresholds, induced currents, zone shield S.E., and protection levels of protective devices. The design margin specification is given in dB and indicates where the design margin is required. Typically, the design margin is specified to be 10 dB at each level of protection. Hence, the designed protection level must be 10 dB better than that level determined from the allocation process of Chapter 4.

3.7 PROTECTION VALIDATION (Ref. 1, 3, 10)

Protection validation is the means of verifying that the selected protection practices have a protection level equal to or exceeding the requirement. The way to specify protection validation is by simply stating what is to be validated and which method is to be employed. The overall verification method usually involves the choice of specifying verification by analysis, verification by limited test, or a combination of the two methods. The actual practices used in accomplishing the specified method of verification are selected during the design and validation practice selection covered in Chapter 5.

3.8 PROTECTION QUALITY ASSURANCE (Ref. 3, 13, 22)

Protection quality assurance involves the procedure and controls employed from the production to operational phase of the facility and equipment development cycle to assure that the designed-in HEMP protection is present and will be maintained in the production units. The specification of protection quality assurance consists of stating that the guidelines given in Chapter 6 through 9 of the handbook will be used during the program or that a certain military document on the subject will be used. A document of this nature covering DCS facilities does not now exist.

3.9 PROTECTION DESIGN CONSTRAINTS

Design constraints are those restrictions which limit the choices available at some point in the protection procedure. The specification of design constraints involves making a statement giving the restriction imposed on a protection process. What design constraints are specified is determined from the design restraints placed on the facilities or equipment that affect their HEMP protection.

3.10 MILITARY SPECIFICATIONS

Applicable military specifications which cover HEMP protection requirements for DCS facilities and equipment are to be specified. The specification number and sections which are applicable are listed. Currently, no military standard covering HEMP protection of DCS facilities and equipment have been released.

DESIGN

SCOPE

The design segment contains two chapters. One covers the allocation process and the other the selection of design and validation practices.

The chapter on allocations describes how to allocate protection to the different elements of facility and equipment. Protection allocation is a well known and proven technique and is the process of distributing the overall protection requirement between the different zone shields and intrinsic zone protection. The goal of the allocation process is to be flexible (i.e., able to deal with all levels of protection problems) and balanced (i.e., sufficient level of protection is allocated to each element).

The chapter contains six different sections, where each deals with an important ingredient of protection allocation. The various sections are: The Allocation Process, Zone Shielding Layers, Coupling Reduction for Zone Penetrations, HEMP Zone Environments, Zone Intrinsic Protection Levels, and Zone Grounding.

The chapter on selection of design and validation practices provides the basis for making trade-offs between and final selection of the various design practices and their means of verification. It includes several tables which summarize the important features of the practices providing assistance to the user in making realistic selections. The chapter contains six sections, each dealing with some aspect of the protection design process for DCS facilities and equipments.

The different sections are: Selection of Practices, Selection of Design Practices for Zone Shielding, Selection of Design Practices for Zone Penetrations, Selection of Design Practices for Intrinsic Protection, Selection of Design Practices for Zone Grounding, and Selection of Protection Validation practices.

INPUT FROM OTHER PHASES

Specification: Equipment and Facility Specifications

Development/Production: The requirement for redesign of protection due to failure of protection validation test or first article inspection.

CHAPTER 4 - PROTECTION ALLOCATION

4.1 ALLOCATION PROCEDURE (Ref. 1, 4, 23)

The allocation of protection is carried out early in the design phase of facility and equipment development, as shown in the generalized protection procedure given in Figure 3.

Reasonable and cost-effective allocation of protection to facilities and equipment elements is derived from an effective shielding and grounding scheme. This protection approach results from the realization that protective devices and techniques alone cannot prevent upset or protect against damage at finite cost.

The shielding and grounding scheme that forms the basis for protection allocation in this chapter is the environmental zoning concept which consists of nested shields and internal regional grounding, as shown in Figure 13. The nested shields are required to provide 100 dB of isolation between the exterior HEMP environment and the small-signal environment of circuits.

Ideally, the shields are continuous, closed, and highly conducting Faraday shields; in practice, they are generally compromised by penetrating conductors and apertures, also illustrated in Figure 13. Implicit in protection by this shielding and grounding scheme is the requirement that shielding violations by penetrations and apertures must be treated with protective devices and techniques at the shield interface point to preserve the integrity of the shield.

A final ingredient in this protection scheme is that intrinsic zone protection for equipment can be substituted for the innermost nested zone shield (i.e., that equipment be procured via specification which will operate in a zone environment that results from less than 100 dB of isolation from the exterior HEMP environment). Allocations should be balanced, in that each area requiring protection should have sufficient and not excessive protection requirements assigned to it.

The principles of protection allocation are as follows.

1. Primary protection by nested zone shields with internal regional "grounding."

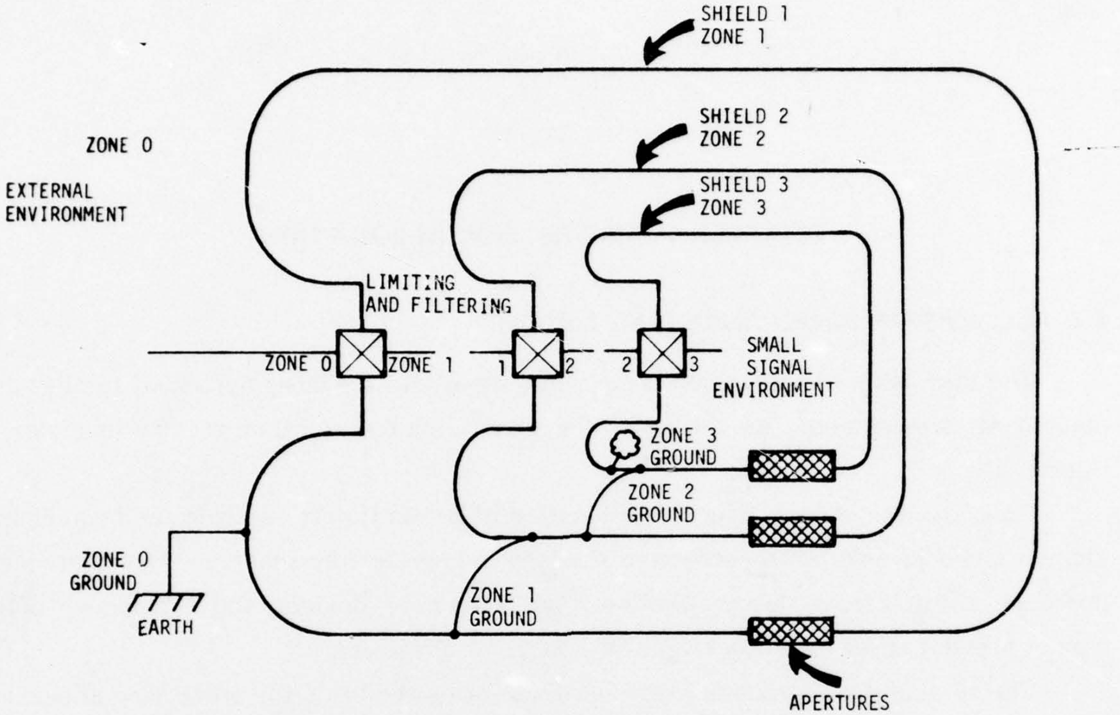

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Figure 13. Nested zone shields with regional grounding

2. The nested zone shields are required to provide a total of 100 dB of HEMP shielding between the exterior environment and the small-signal environment of the electronic circuits.

3. The required level of HEMP shielding is distributed among the zone shields where a shielded enclosure must provide a minimum of 15 dB to be classed as a zone shield.

4. The internal conductors and metal structures within each zone, such as equipment enclosures, cable trays, shields, and conduits which are not intentionally at a potential different from the shield potential, should be connected to the zone shield. This includes the shield of the next inward zone shield.

5. Zone shield penetrations must be treated to provide a coupling reduction of induced transients by a factor equal to the shielding effectiveness of the zone shield plus 10 dB.

6. Zone shield apertures must be treated so that they have an HEMP shielding effectiveness which is equivalent to that for the zone shield.

7. Intrinsic zone protection for equipment can be allocated to equipment levels for operation in innermost zone environments in place of providing 100 dB of isolation between the exterior environment and the equipment. For practical intrinsic zone protection levels, the total HEMP shielding can be reduced to 70 dB.

To initiate the allocation process, the user needs to determine his function (F) and function level (FL). If the user's F $\neq$ B, then it is not his function to perform allocation and he should pass over this chapter.

The user allocation matrix is shown in Table 3. Employing his FL value, the user establishes from the matrix what allocations he is to make. Note that the user with FL = 1 can achieve maximum flexibility and balance in his allocations, since he can provide allocation protection to all areas of a facility. The matrix provides the allocation quantity and the section which should be consulted in making the allocation.

4.2 ZONE SHIELDING LAYERS (Ref. 1, 3, 4, 5)

The volume enclosed by a perfect shield is an equipotential region, there is no penetration of electric or magnetic fields through the shield, and all current or charges injected on the outside surface remain outside. There are no gradients of external origin within the shield or volume which it encloses.

In reality, shields are not perfect conductors. Hence, the external fields are not quite completely reflected and currents injected on the outside penetrate into the shield, as shown in Figure 14. However, as long as the shield thickness is large compared to the skin depth (δ), the fields and currents levels produced inside the shield by external sources are drastically reduced from the outside levels. Thus, shields protect the enclosed region against interference of external origin and provide an equipotential region within the shield volume.

For common shielding materials, such as steel, aluminum, and copper, a closed shield a few mils thick is capable of reducing the ambient external field by 100 dB

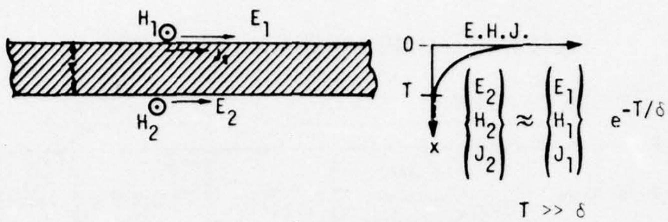
TABLE 3. PROTECTION ALLOCATION MATRIX

FL	ALLOCATIONS												
	EXTERIOR ENVIRONMENT 4.4	ZONE ENVIRONMENT 4.4	ZONE INTERFACE LEVELS 4.4	BUILDING S.E. 4.2	ENCLOSURE S.E. 4.2	COMPONENT S.E. 4.2	COUPLING REDUCTION FOR EXTERIOR CABLES 4.3	COUPLING REDUCTION FOR BUILDING PENETRATIONS 4.3	COUPLING REDUCTION FOR ZONE PENETRATIONS 4.3	SYSTEM EQUIPMENT S.E. 4.2	INTRINSIC PROTECTION LEVEL 4.5	EXTERIOR GROUNDING 4.6	ZONE REGION GROUNDING 4.6
1	*	*	*	*	*	*	*	*	*	*	*	*	*
2	*						*					*	
3	*			*				*				*	*
4		*							*				*
5		*	*		*							*	*
6		*	*			*						*	
7		*	*							*	*		*

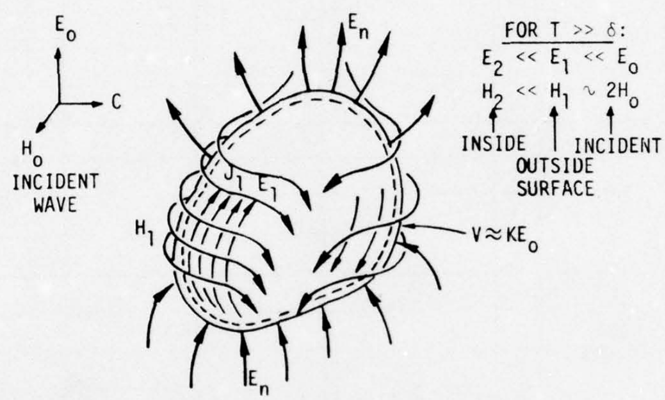
inside the shield. In practice, the performance of a shield is usually not governed by the thickness, permeability, or conductivity of materials (as these are usually sufficient) but rather by the defects that exist within the shield. These defects include the presence of minute apertures arising from construction or large apertures, such as vents, doors, and seams, as well as various types of penetrations (e.g., cables and pipes through the shield).

Almost any metal shield is sufficient to reduce the incident electric field to a negligible value. Hence, for HEMP the only shielding quantity of interest is the magnetic shielding. The HEMP shielding effectiveness of a shield is defined as the ratio of the peak incident to the peak interior field:

$$S.E._{HEMP} = 20 \log \frac{H_i(t)\ \text{PEAK}}{H_z(t)\ \text{PEAK}} \quad . \qquad (4.1)$$



(a) Decay of electromagnetic fields and current density in shield



RT-16886 **(b) External fields about a closed shield**

Figure 14. Electrodynamic shield (Ref. 4)

Shields having shielding effectiveness above 60 dB are difficult to construct and maintain. Consequently, protection usually is accomplished through one or more shielding layers, where each boundary has to be complete in the sense that apertures, penetrations, and grounding must be properly dealt with to preserve the protection to be gained at that layer.

The 100 dB of HEMP isolation required in a facility is thus distributed between the building (or van for mobile installations), cable shielding (shields, cable trays, and conduits), enclosures, components, and enclosure/component combinations. The allocation of shielding is made on the basis of shielding specification, effectiveness, cost, reliability, feasibility, and design restrictions. Table 4 provides most of the information required to perform the allocation process for shielding.

The allocation procedure for shielding is given in Figure 15. In constructing or establishing the nested zone shielding topology, the more interference-free environments are identified by larger zone numbers and have a greater number of shields between them and the exterior environment. Although zones have been depicted as a series of concentric regions, they usually assume an irregular form, since they correspond with the major geometric featuers of the facility/equipment.

TABLE 4. ZONE SHIELDING LAYERS

Shield Type		HEMP Shielding Effectiveness	Cost $/sq. ft.	Feasibility	Reliability
Building	1				
	2				
	3				
	4				
Van	1				
	2				
	3				
	4				
Cable Shields	1				
	2				
	3				
	4				
Cable Trays	1				
	2				
	3				
Conduits	1				
	2				
	3				
	4				
Enclosures	1				
	2				
	3				
Component	1				
	2				
	3				
Enclosure Components	1				
	2				
	3				

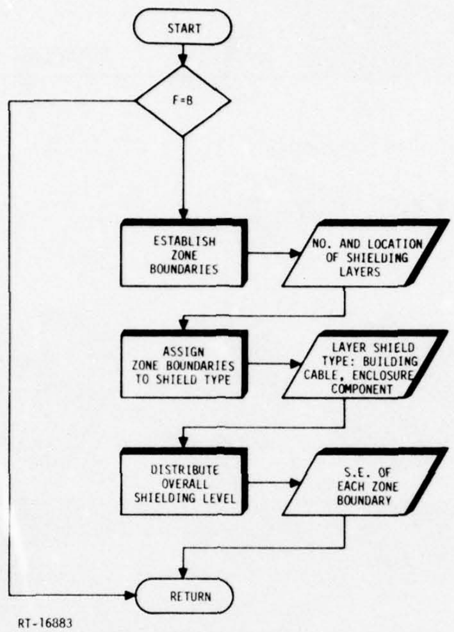


Figure 15. Shielding allocation procedure

In establishing nested zone shields for complex cases, it often is helpful to resort to the use of cross hatching and shading as illustrated in Figure 16. to keep track of zonal identifications. Shields are required to have at least 15 dB of shielding effectiveness to be classed as a zone shield. Some possible distributions of shielding are given in Table 5. Note that zone shield apertures are to be specified to have the same shielding effectiveness as the zone shield.

TABLE 5. SAMPLE SHIELDING DISTRIBUTIONS

Building S.E. (dB)	Cable (Shield/ Conduit/Tray) S.E. (dB)	Enclosure S.E. (dB)	Component S.E. (dB)	Enclosure/ Component S.E. (dB)
100	--	--	--	--
60	--	40	--	--
60	--	--	40	--
60	--	--	--	40
40	60	60	--	--
30	--	35	35	--
0	50	50	50	--

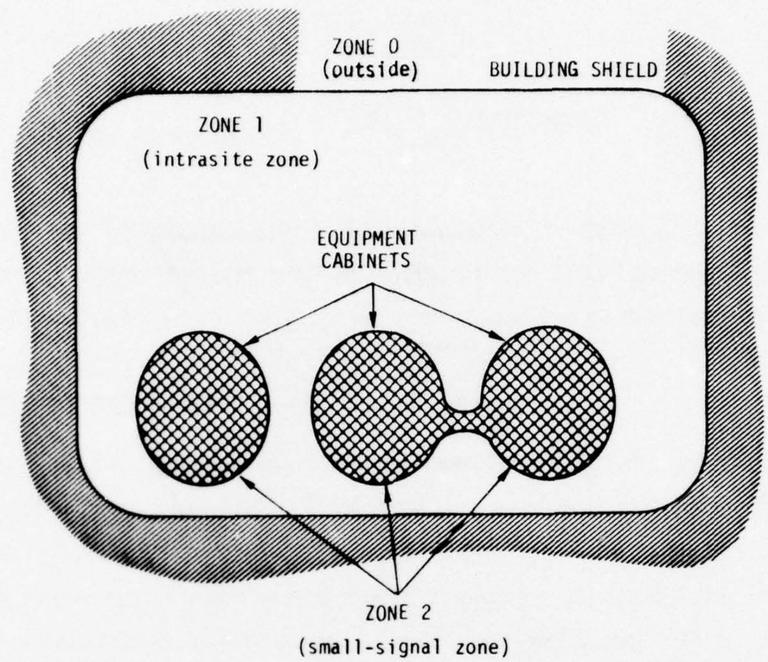


Figure 16. Nested shield identification using cross hatching and shading

4.3 COUPLING REDUCTION FOR ZONE PENETRATIONS (Ref. 16)

A zone penetration is any conductor that goes through some facility or equipment zone shield and serves as a path along with electromagnetic energy from the outside zone propagates into the next zone and affects its environment. Some common penetrations (illustrated by Figure 17) are power conductors, communication cables, signal cables, waveguides, antennas and their connecting cables, water and sewage pipes, external lighting conductors, fuel and exhaust pipes, air ducts, ground conductors, external fire extinguishers, and wiring for intercom and public address systems.

The currents and voltages induced on zone penetrations can be dealt with by appropriate treatment at the point where the conductor enters the zone shield. These treatments usually consist of protective techniques utilizing diversion, reflection, and absorption. These basic techniques are illustrated in Figure 18.

The major result for this section is to allocate the coupling reduction required for the zone penetrations. The following procedure is used:

1. Identify all penetrations for each zone shield of concern to the user.

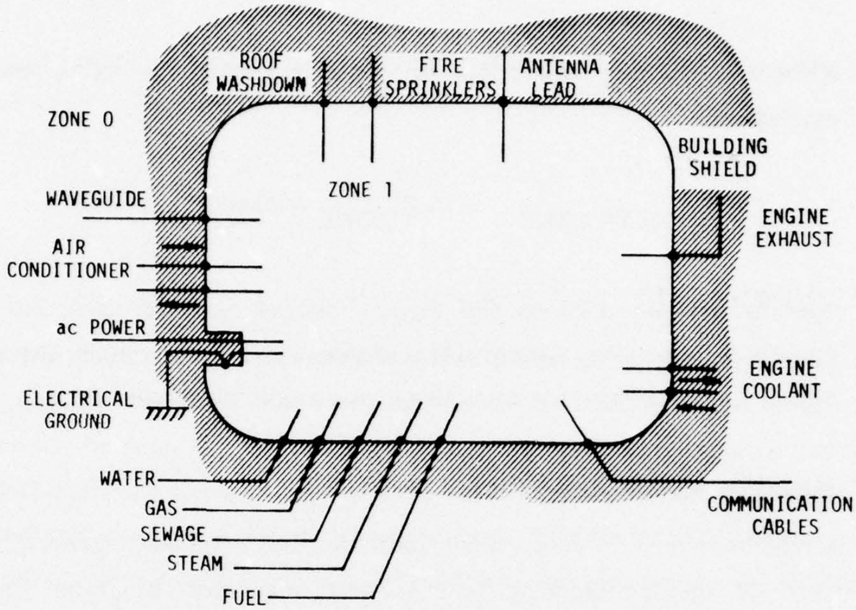


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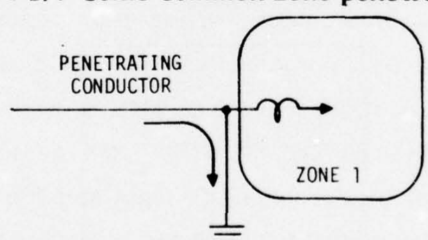
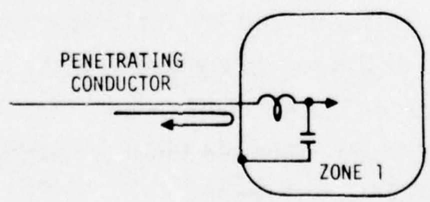
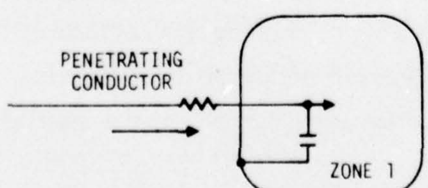
Figure 17. Some common zone penetrations



(a) Diversion



(b) Reflection



(c) Absorption

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Figure 18. Some basic methods of treating zone penetrations

2. Allocate coupling reduction to these penetrations using the following expression:

$$C.R._{PENETRATIONS} = S.E._{ZONE} + 10\text{ dB} \quad . \qquad (4.2)$$

3. Specify the penetrations and their allocated coupling reduction. This procedure is adequate, except for antennas and their connecting cable. The allocation procedure for this case is not available at this time.

4.4 HEMP ZONE ENVIRONMENTS (Ref. 1, 5, 18, 24)

As described earlier, communication facilities and equipment generally consist of several regions of electromagnetic environment separated by zone shields. For example, a building shield separates the severe external environment from the more moderate room environment, and the equipment enclosure separates the room environment from the small-signal environment inside the enclosure. It is important to determine the expected zone environment once the shield allocations have been made for use in design practices selection, as well as setting intrinsic protection levels. The environmental quantities of interest are the worst case magnitude and time behavior of the direct-coupled component of the magnetic field and the worst case magnitude and time behavior of the induced current, including the effective source impedance.

The magnetic shielding effectiveness of shields has a low-pass response. Thus, the fields inside the shield will be dominated by the frequencies below the attenuation cutoff. This basic response is altered to some degree by the presence of apertures, which reduce the high attenuation in the cutoff region. The shield drastically alters the incident magnetic pulse which penetrates the shield, reducing its amplitude, increasing its rise time, and stretching out the fall time.

The magnetic field inside zone 1 will be a double exponential pulse with the characteristics given in Table 6. For rectangular enclosures the sphere geometry should be used where 2r is the smallest dimension of the enclosure. The magnetics field levels in other zones can be obtained by using the S.E. of the zone shields which gives

$$H_{Z(PEAK)} = \frac{H_{I(PEAK)}}{\log^{-1}\left(\frac{S.E._{HEMP}}{20}\right)} \qquad (4.3)$$

where $H_{I(PEAK)}$ is the peak value of the field external to the zone of interest. The pulse will again be a double exponential with rise and decay times obtained by

$$\tau_{RN} = \sqrt{\tau_{R1}^2 + \tau_{R2}^2 + \ldots \tau_{Rn}^2} \tag{4.4}$$

$$\tau_{DN} = \sqrt{\tau_{D1}^2 + \tau_{R2}^2 + \ldots \tau_{Dn}^2} \tag{4.5}$$

where τ_{RN} is the (10-90%) rise time for the Nth zone, τ_{DN} is the $(\frac{1}{e})$ decay time for the Nth zone and the different τ are obtained for the corresponding zones using the appropriate expressions given in Table 6.

TABLE 6. MAGNETIC FIELD PARAMETERS FOR ZONE 1 (Ref. 24)

Geometry	ξ	H_z (peak)	$\dot{H}_z$ (peak)	Rise Time (10-90%)	Decay Time (1/e)
Single plate	$\frac{Z_o}{R}$	$\frac{6 H_o}{\xi t_\Delta}$	$\frac{120 H_o}{\xi t_\Delta^2}$	$\frac{t_\Delta}{20}$	$\frac{t_\Delta}{\pi^2}$
Parallel plates	$\frac{\mu_o r}{\mu \Delta}$	$\frac{H_o}{\xi t_\Delta}$	$\frac{6 H_o}{\xi t_\Delta^2}$	$\frac{t_\Delta}{4}$	ξt_Δ
Cylinder	$\frac{\mu_o r}{2\mu \Delta}$	$\frac{H_o}{\xi t_\Delta}$	$\frac{6 H_o}{\xi t_\Delta^2}$	$\frac{t_\Delta}{4}$	ξt_Δ
Sphere	$\frac{\mu_o r}{3\mu \Delta}$	$\frac{H_o}{\xi t_\Delta}$	$\frac{6 H_o}{\xi t_\Delta^2}$	$\frac{t_\Delta}{4}$	ξt_Δ

δ is conductivity of shield
Δ is shield thickness
μ_o is free space perability
μ is permeability of shield
$t_\Delta = \mu \delta A^2$ is diffusion time constant
$Z_o = 377\Omega$ is free space impedance
$R = (\delta\Delta)^{-1}$ is dc skin resistance
H_o is amplitude of incident field
H_z is zone 1 field

The major component of induced current will be produced by $\dot{\beta}$ coupling to loops in the intrazone wiring. The worst case bulk current amplitude is given by

$$I_p = \frac{\mu_o H_{Z(PEAK)} A}{t_W R_S} ,$$

where R_S is the source impedance and is about 100Ω, μ_o is the permeability of free space, $H_{Z(PEAK)}$ is the peak amplitude of the zone field, A is the area of the loop (usually taken as the largest practical loop which the zone could contain), and t_W is the zone field pulsewidth. Thus, once the zone field amplitude and pulsewidth is determined, the induced current can then be calculated. Typical calculated worst case bulk currents on intrazone wiring for AUTOVON switching centers are shown in Table 7.

TABLE 7. WORST CASE INDUCED BULK CABLE CURRENT FOR INTRA ZONE WIRING (Ref. 18)

Zone Shield S.E. (dB)	I_p (amp)
0	37.5
10	12
20	3.8
30	1.2

4.5 ZONE INTRINSIC PROTECTION LEVELS (Ref. 1, 4)

Zone intrinsic protection levels can be allocated to equipment in place of some zone shielding, thereby reducing the required nested zone's total shielding level by up to 30 dB. The H-field environment and the interface current level are assigned to the equipment as their operational environment and, thus, become the responsibility of the equipment supplier. The environments to be specified are determined from the previous section.

The procedure for this allocation is as follows.

1. Determine the nested zone's shielding effectiveness allotted to the equipment intrinsic protection.

2. Calculate the worst case H-field environment and the worst interface current level.

3. Specify this environment as an operational requirement for the equipment selected for this allocaiton.

4.6 ZONE GROUNDING (Ref. 1, 3, 4, 16)

Integral to the concept of HEMP protection by shielding is a complementary grounding scheme. The grounding system for facility and equipment consists of two distinct elements: the exterior and the zone grounding. The exterior ground attempts, in a field-significant way, to connect to the large, but poor, rational conductor which covers the earth's surface. This ground is particularly important, as it serves as a sink to which shield and penetration currents are diverted. The external ground should be allocated on the basis that the ground has a low impedance and should be distributed for ease of connection and to minimize earth gradients across the facility. The ring ground meets all of these requirements and is a counterpart of the zone grounding discussed next.

The equipotential region within zones can be disturbed by internal sources or charge displacements. Thus, all internal conductors and structures, such as equipment enclosures, cable trays, shields, and conduits, which are not intentional at a potential different from the shield potential should be connected to each other and to the inside surface of the shield. This common "grounding" approach includes even the outside of the shield enclosing the next inward zone. This grounding scheme is known as regional zone grounding and results in an overall internal ground tree. Thus, regional grounding is allocated to this grounding method.

CHAPTER 5 - SELECTION OF DESIGN AND VALIDATION PRACTICES

5.1 SELECTION OF PRACTICES (Ref. 1, 3)

To use this chapter the user function should be equal to C. The user matrix identifying the design and validation practices and the pertinent section in Chapter 10 for the different users is given in Table 8.

5.2 SELECTION OF DESIGN PRACTICES FOR ZONE SHIELDING

The design practices for zone shields include shielding practices for buildings, enclosures, equipment components, and cable shields. The level of shielding effectiveness required for the zone shield should have been previously determined by the allocation process given in Chapter 4. Several factors enter into the selection of one shielding practice over another. Some of the factors are: effectiveness, cost, reliability, flexibility, portability, and design constraints.

Theoretically the effectiveness of shields is determined by their size, material type, and thickness. In practice the actual effectiveness is limited by various penetrations and apertures. Hence, selection of a specific shielding practice with a certain effectiveness will require selection of a complimentary treatment of penetrations, apertures, and grounding.

Effectiveness, cost, and reliability are interrelated. As expected, when the required effectiveness increases so do the costs and the maintenance requirements for reliable operation. Shielding values over 60 dB utilize modular seamless (drawn) or seam-welded shield designs and result in difficult assembly, maintenance, and measurement requirements in addition to higher costs and the necessity of using more sophisticated access methods.

Portability or transportability places special requirements on shields as they are subject to a substantial amount of flexure in transit. Consequently, these shields are usually required to be seam welded. The integrity of the access doors and other apertures seals become the limiting factor in the shields' attenuation performance due to degradation with structure flexing. Transportable shields typically exhibit 20 to 30 dB less shielding than their stationary counterparts.

TABLE 8. USER MATRIX FOR SELECTION OF DESIGN AND VALIDATION PRACTICE

DESIGN AND ASSURANCE PRACTICE SELECTION \ FL	1	2	3	4	5	6	7
BUILDING SHIELDING 10.1.1	X	–	X	–	–	–	–
CABLE SHIELDING 10.1.4	X	X	–	X	–	–	X
COMPONENT SHIELDING 10.1.3	X	–	–	–	–	X	X
ENCLOSURE SHIELDING 10.1.2	X	–	–	–	X	–	X
APERTURE TREATMENT 10.1.5	X	–	X	–	X	X	X
EXTERIOR GROUNDING 10.4.1	X	X	X	X	–	–	X
ZONE GROUNDING 10.4.2	X	–	X	X	X	X	X
PENETRATION TREATMENT 10.2	X	X	–	X	X	X	X
NON-ELECT PENETRATION TREATMENT 10.2.11	X	–	X	–	X	X	X
NON-CRITICAL POWER PENETRATION TREATMENT 10.2	X	–	X	–	–	–	X
LENGTH AND PHYSICAL LOCATION OF PENETRATIONS 10.2.9-10	X	X	–	X	–	–	X
SIGNALING MODE 10.2.3-6	X	X	–	X	X	X	X
VALIDATION METHOD 10.5	X	X	X	X	X	X	X
HIGH LEVEL CIRCUITS 10.3.1	X	–	–	–	X	X	X
U.P.S. 10.3.2	X	–	X	–	–	–	X

Shielding requirements can be fulfilled by selecting a shield practice that incorporates shielding as an structural part of the enclosing structure. Examples of this are: reinforced concrete building with welded rebar; metal building and vans; equipment enclosures and equipment components. In other cases the shielding practice is to select shielding materials which are placed on the outside or inside of non-shielded enclosures. Thus the shield plays no structural role and acts soley as an electromagnetic shield. Examples of this practice employ metal screens, conductive finishes, metalized wallpaper, and foils.

Design constraints limit the shielding practices which can be selected since the shielding technique must be compatable with the requirement as well as the restrictions. Some design constraint examples are fixed cost, existing facility, transportability, specified material, or construction technique.

The procedure for selecting design practices for building shielding utilizes Table 9 along with the following procedure:

1. Determine required shielding effectiveness for building shield which is usually given by a specification or obtained from the allocation process of Chapter 4.

2. Define cost and design limitations.

3. Define special requirement such as transportability or special construction considerations.

4. Consult Table 9 to select the shielding practice that fulfills the above requirements.

5. Review design practices summaries given in Chapter 10 to verify the selection.

6. If the selection is adequate, use the appropriate details on the practices given in Appendix A of Part II to be included in the design drawing and specification of the building.

7. If the selected practices are not adequate, iterate the selection process or return to the allocation process for possible alteration of the building shielding allocation.

Similar discussions and procedures should be given for the other practices. Table 10 through 12 are for use in these discussions.

TABLE 9. SUMMARY OF DESIGN PRACTICES ON BUILDING SHIELDING

BUILDING TYPE	S.E. (dB)	COST ($/SQ. FT.) 1978	RELIABILITY	CHAPTER 10 SECTION #	SPECIAL CONSIDERATIONS

TABLE 10. SUMMARY OF DESIGN PRACTICES ON EQUIPMENT ENCLOSURES

ENCLOSURE TYPE	S.E. (dB)	COST ($/Cu. ft)	RELIABILITY	CHAPTER 10 SECTION #	SPECIAL CONSIDERATION

TABLE 11. SUMMARY OF DESIGN PRACTICES FOR COMPONENT SHIELDS

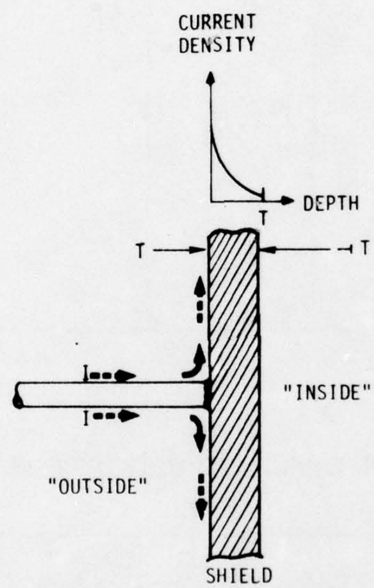
COMPONENT TYPE	S.E. (dB)	COST ($/Cu. ft)	RELIABILITY	CHAPTER 10 SECTION #	SPECIAL CONSIDERATIONS

TABLE 12. SUMMARY OF DESIGN PRACTICES FOR CABLE SHIELDS

SHIELD TYPE	S.E. (dB)	COST ($/ft.)	RELIABILITY	CHAPTER 10 SECTION #	SPECIAL CONSIDERATIONS

5.3 SELECTION OF DESIGN PRACTICES FOR ZONE PENETRATIONS

The design practices for reducing HEMP transients coupled to zone shield penetrations take several forms. One of the more important classes of practices involves current diversion and utilizes the fact that currents in conductors attached to shields flow predominantly on the outside surface of the shield. This practice, which is illustrated in Figure 19, results from the skin effect in conductors. Practices which fall into this category are circumferential termination, filters, and surge arrestors.



RT-16898

Figure 19. Confinement of conductor current to the "outside" surface by the skin effect

Another class of practices use reflection and cancellation for coupling reduction and involve techniques such as specialized signaling methods, impedance changes, and nonelectrical isolation. The practices in this category include balanced signaling with twisted pairs, fiber optics, dielectric sections for waveguides and piping, and ground planes. Note that many of the practices listed in the above two categories actually utilize both current diversion and reflection.

A third class of design practices for penetrations employs absorption, where the transient currents and fields are dissipated in a resistive medium. Cable burial is in this category. The final class of penetration design practices uses physical alterations to reduce induced transients. In this category are loop and length minimization, separation, and clustering.

The level of coupling reduction required for individual penetration zone shields is dependent on the zone shields S.E., and is determined by the protection allocation process in 4.3, and is given in dB. Factors affecting the selection of practices for treatment of penetrations are: effectiveness, cost, relevancy, realizability, and reliability.

Effectiveness of a practice is the dB reduction in coupling provided by its use. Cost, of course, is the relative cost associated with procuring and implementing the practice. Relevancy concerns whether the candidate practice is realistic for the application. Realizability refers to whether the effectiveness required of the candidate practice can be achieved. Reliability is a measure of the likelihood that the penetration treatment will continue to provide the required coupling reduction throughout its useful life.

Candidate practices are selected to have an effectiveness that equals or exceeds the required coupling reduction for that particular penetration. Cost, realizability, and reliability are related to effectiveness. Requirements for increased levels of effectiveness for penetration practices leads to increased cost and reliability requirements. Each practice has an inherent effectiveness level which in most cases requires some care to realize and maintain at that level upon implementation. For example, for surge arrestors to exhibit maximum effectivenss requires special treatments on installation, such as minimizing lead inductance, installation at point of protection, enclosure in a shielded box, and minimization of effective loop area.

The procedure for selecting design practices for penetrations is shown symbolically in Figure 20 and is given below.

1. Determine the required coupling reduction and a description of each penetration. The required coupling reduction should be given by a specification or obtained from the allocation procedure in 4.3.

2. Define cost, installation, and design limitations.

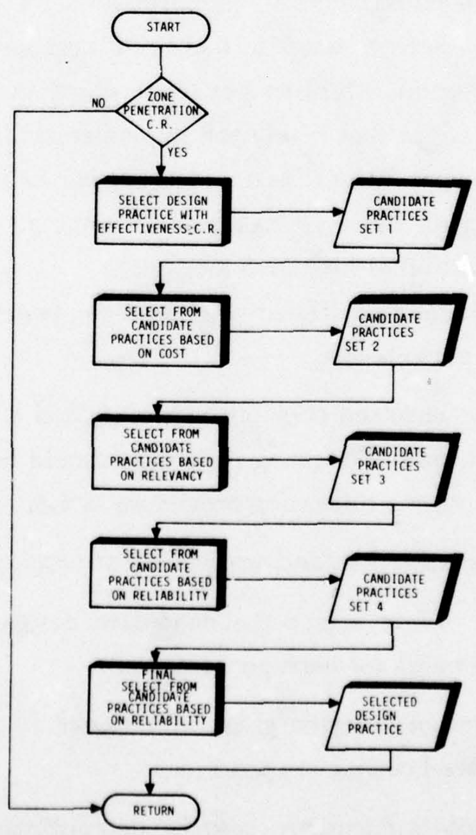
3. Consult Table 13 to select the candidate design practices that fulfill all known requirements for each penetration.

4. Review the design practice given in Chapter 10 to verify selection and to establish required companion practices.

5. If the selection is adequate, use the appropriate details on the practices given in Appendix A of Part I for inclusion in design drawings and specifications.

TABLE 13. DESIGN PRACTICES FOR PENETRATIONS

DESIGN PRACTICE	RANGE OF EFFECTIVENESS (dB)	RELATIVE COST	RELIABILITY	APPLICATION	SPECIAL REQUIREMENTS



RT-16896

Figure 20. Procedure for selecting design practice for penetrations

6. If the selected practices are not adequate, iterate the selection process or return to the allocation process for possible alteration of the coupling reduction requirement.

5.4 SELECTION OF DESIGN PRACTICES FOR INTRINSIC PROTECTION

Design practices for intrinsic protection consists of devices, circuits, or equipment which have an inherent measure of protection against the effects of HEMP-induced transients. Uninterruptible power supplies (UPS), high-threshold logic (HTL), and read-only memories (ROM's) are design practices for intrinsic protection.

The UPS is increasingly utilized for critical installations to protect against all transient disturbance of facility power. The UPS has a significant level of intrinsic protection against HEMP-induced damage and upset because of its design to handle incoming transients. HTL and ROM's have an inherent measure of protection against upset, but they are susceptible to damage.

Factors to consider in selecting the practices of intrinsic protection are cost, effectiveness, relevancy, and reliability. The selection process should be based on a procedure similar to that given for penetrations.

5.5 SELECTION OF DESIGN PRACTICES FOR ZONE GROUNDING

Zone grounding design practices are to provide an equipotential distribution between dominant structural members and the surrounding natural environment. The grounding practices fall into two categories: exterior and zone. Viable practices in both categories are limited because most current grounding schemes in use are inadequate for transient environments. Hence, the selection process for grounding design practices is unnecessary, as only one practice for each category is recommended. For the exterior environment, the ring ground is the preferred practice, as it provides a low-impedance, distributed connection to earth. For the nested zones, regional zone grounding is the practice which should be used, as it provides a low-impedance connection to the equipotential region formed by the zone shield.

5.6 SELECTION OF PROTECTION VALIDATION PRACTICES

Validation practices are test or analysis methods used to verify that the expected protection level of a design practices is achieved upon implementation. Validation

practices generally are employed during the prototype development phase and for the protection validation milestone tests performed on the prototype unit upon completion.

The selection of these practices is made on the basis of the specified validation requirements, relevancy, cost, and need. The method of validation or the requirements for validation generally are set forth in the unit specification. Relevance refers to whether the validation practice pertains to the design practice that one is desiring to validate. Cost, of course, concerns how much it will cost to utilize the validation method. Need relates to whether it is really necessary to validate the design practice. The selection procedure for validation practices should be similar to that given for shielding and penetration practices.

PROTECTION QUALITY ASSURANCE

SCOPE

Protection Quality Assurance are the procedures required to assure that the HEMP protection designed into equipment and facilities is maintained at an acceptable level throughout their life. Each of the chapters in this segment concerns some important element of a systematic program of protection quality assurance for DCS facilities and equipment. Some of the factors covered are: specification, required equipment production controls, special construction and installation procedures, requirements for inspection and acceptance tests, and maintenance and surveillance requirements.

INPUT FROM OTHER PHASES

Design phase: The design and validation practices selected to provide protection

Development: Protection assurance procedures for production

Production: Installation and acceptance plans

Installation: Protection assurances procedures for operation.

CHAPTER 6 - PRODUCTION/PROCUREMENT/CONSTRUCTION ASSURANCE PROCEDURES

6.1 PROCUREMENT PROCEDURE (Ref. 13)

Facility and equipment protection, once designed and demonstrated, could be lost during procurement unless all protection requirements are properly understood, documented and included in the production controls on procured end items. Thus a procurement protection assurance procedure is prepared during the development phase so that end item procured during production will provide the required protection. Elements to be considered in the section are:

1. Detailed Drawings
2. Parts and Equipment Protection Specifications (Parts and equipment specifications should be developed to reflect the requirements and characteristics necessary to conform with the baseline designed protection) (Ref. 22).
3. Special Requirements
4. Accept/Reject Criteria
5. Handling and Accountability

6.2 PRODUCTION PROCEDURES (Ref. 1, 13)

In parallel with the procurement protection assurance activities, a Production Protection Assurance Plan will be prepared. The objective of this plan is to document all production oriented protection assurance requirements and activities. Activities to be covered in this plan include manufacturing controls and procedures, documentation, special production personnel training, inspection and testing for end item protection.

Some of the topics to be discussed in the Production Assurance Procedures are as follows.

1. Production Controls

2. Special Procedures, Tools, Manuals, and Aids

3. Inspection and Quality Control Tests

4. Rework Procedures

6.3 CONSTRUCTION PROCEDURES

Protection Assurance Procedures for construction are also prepared during the Development Phase, if applicable. This procedure discusses the practices, controls, inspections, and tests required to assure that the HEMP protection is designed in the facility and verified. The key aspects of the Construction Protection Assurance Procedure involve:

1. Construction Practices

2. Configuration Control

3. Inspection and Tests

CHAPTER 7 - INSTALLATION PROTECTION ASSURANCE PLAN

7.1 PERSONNEL (Ref. 11, 13)

Facilities and/or Equipment properly designed, demonstrated, and manufactured can be lost by improper installation. Those carrying out the installation must be aware of the protection requirements and how it is to be achieved and assured. Thus the Installation Protection Assurance Plan sets forth the supervision, certification, and instructions of personnel regarding the HEMP protection requirements of the facility and the equipment during installation. The subjects to be discussed are listed below:

1. Skill and Awareness
2. Personnel Certification
3. Supervision.

7.2 CONTROLS

The controls necessary to assure protection during installation are considered in this section. The elements in this section include accountability for parts, inspection and tests, and control of the installation process as follows:

1. Parts and Component Accountability
2. Assembly Inspection and Test
3. Work Orders.

CHAPTER 8 - FACILITY AND EQUIPMENT ACCEPTANCE PLANS

8.1 EQUIPMENT ACCEPTANCE PLANS

This section describes the requirements for and how to prepare the protection assurance portion of an Equipment Acceptance Plan. The plan includes discussions of specified acceptance tests, the frequency of testing, acceptance criteria and correlation with previous tests. The major factors to be included in this section are as follows:

1. Test Specifications
   a. Direct Tests
   b. Protection Tests
   c. Baseline Tests
2. Sampling Requirements
3. Acceptance/Rejection Criteria
4. Reconciliation With Validation Tests

8.2 FACILITY ACCEPTANCE PLAN

Protection assurance considerations in Facility Acceptance Plans are considered in this section. Major activities to be included in the Facility Acceptance Plan are the examination of various inspection and tests results for the facility during the construction and installation, an inspection of the facility to assure it meets the various documented requirements, and, finally, demonstration tests to prove compliance. Elements to be discussed include:

1. Record Examination
   a. Inspection Results
   b. Equipment Tests
2. Facility Inspection
   a. Procedures
   b. Correlation With Requirements
3. Demonstration Tests

CHAPTER 9 - PROTECTION ASSURANCE PROCEDURES FOR OPERATION

9.1 MAINTENANCE (Ref. 11, 13)

The ideal HEMP protected facility would of course be maintenance free. Unfortunately all practical cost effective facilities require maintenance. Hence maintenance procedures and schedules must be prepared for HEMP protection control. These procedures should be coordinated with and integrated into existing maintenance plans when possible. The Protection Maintenance Procedure should be developed during the Installation/Acceptance phase and cover such topics as maintenance, spare parts, training of maintenance personnel, records, inspection, and failure analysis of failed units.

9.2 MODIFICATION AND CHANGE PROCEDURE

Modification and changes to facilities and equipment can alter their HEMP protection. Thus Modification and Change Procedure must be developed to assure that the HEMP protection is maintained. This section covers what the procedure should contain and how to prepare it. Such subjects as specification review, conformance, acceptance, and demonstrations tests are discussed.

9.3 SURVEILLANCE (Ref. 1, 11-13)

The quantitative measurement of DCS facilities and equipment operational protection is a necessary aspect of Protection Quality Assurance. This measurement is accomplished through a program of Protection Surveillance. The intent is to obtain measurements of facility/equipment protection, to interpret data in terms of meaningful protection assurance parameters, and to recommend protection improvements if required.

Large scale tests of facilities and equipment are usually too expensive. Thus the surveillance procedure should employ statistical spot checks of facilities and equipment utilizing various screens, and limited tests to periodically verify their protection status. The following topics are covered in this section: periodic inspection, periodic tests, correlation of data, failure analysis, and rework procedure.

DESIGN AND VALIDATION PRACTICES SUMMARY

SCOPE

The summary of each design and validation practice are contained in this segment. The summaries are based on the material given in the in-depth treatment of design and validation practices of Appendix A, Part 2. It is through the selection and implementation of a self-consistent set of design and validation practices given in this segment that facilities and equipment will have verified protection against HEMP.

This segment contains a single chapter having five sections in which each covers the categories of the design and validation practices. The sections are: Zone Shielding, Zone Penetrations, Zone Intrinsic Protection, Zone Grounding, and Protection Validation.

INPUT FROM OTHER PHASES

Design: The allocation of protection and the selection of practices

Appendix A, Part 2: Greater details about the practices if required.

CHAPTER 10 - SUMMARY OF PROTECTION DESIGN AND VALIDATION PRACTICES

This chapter provides summaries of each design and validation practice. The summaries are a compilation of materials from the in-depth discussion of design and validation practices given in Part 2, Appendix A. The summaries are primarily tabular in form and employ simple sketches where applicable.

The information and data covered in the summaries is that required for practice selection. The summaries are basically to provide users with a compact source of information on each of the design and validation practices, thus not exposing the user to detailed material (to avoid confusion) unless it is required.

As design and validation practices are formulated and added to Appendix A in Part 2, a corresponding summary can be prepared and placed in this chapter.

Two examples of design practice summaries are given in Tables 14 and 15.

10.1 ZONE SHIELDING

The practice summaries for zone shielding will be contained in this section.

10.2 ZONE PENETRATIONS

The practice summaries for zone penetrations will be contained in this section.

10.3 ZONE INTRINSIC PROTECTION

The practice summaries for zone intrinsic protection will be contained in this section.

10.4 ZONE GROUNDING

The practice summaries for zone grounding will be contained in this section.

10.5 PROTECTION VALIDATION

The practice summaries for protection validation will be contained in this section.

TABLE 14. DESIGN PRACTICE SUMMARY FOR BUILDING SHIELDING

DESIGN PRACTICE: BUILDING SHIELDING
APPLICATION: ZONE 0/1
EFFECTIVENESS: 15 to 120 dB
DIFF. COST RANGE: 10 to 90 (1978 $/Sq. Ft.)
REQ. ASSOCIATED PRACTICES:
APERATURES
PENETRATIONS
GROUNDING
DESIGN DATA:

DESIGN PRACTICE	HEMP S.E.	COST (1978 $/Sq. Ft)	CONSTRUCTION	SPECIAL CONDITIONS

ENGINEERING SKETCH:
(SKETCH OF EACH TYPE OF DESIGN PRACTICE)
VENDORS:

TABLE 15. DESIGN PRACTICE SUMMARY FOR SEMICONDUCTOR SURGE ARRESTORS

DESIGN PRACTICE: SURGE ARRESTORS/SEMICONDUCTORS

APPLICATION: ZONE PENETRATIONS

EFFECTIVENESS: 30-60 dB

DIFF COST RANGE: 1 to 10 (1978 $)

REQ. ASSOCIATED PRACTICES:

- SHIELDING
- APERTURES
- GROUNDING
- SURGE ARRESTOR INSTALLATION
- LOW SHUNT CAPACITY ARRANGEMENT
- HYBRID SURGE ARRESTORS

DESIGN DATA:

Vendor	Device Number	Clamping Voltage (V)	Surge Current (I) 100 nsec (A)	Surge Impedance (Ω)	Shunt Cap (pf)	Leakage (μA)	Wattage, (W)	Comments

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PART 2 APPENDICES

APPENDIX A - PROTECTION DESIGN AND VALIDATION PRACTICES

This appendix is to be the repository for protection design and validation practices as they are developed. The in-depth discussion of each practice includes its rationale, analytical basis, and description as well as its effectiveness and the factors which should be considered in selection of the practice. The practices include blue prints, line drawings, and sketches as required. In addition the following data and information is to be provided when applicable: vendor names, pertinent parameters for parts, part numbers, part types, specifications for parts procurement, guidelines, procedures, special materials, and special treatments.

The practices are currently organized into five categories: zone shielding, zone penetrations, zone intrinsic protection, zone grounding, and protection validation. This categorization corresponds to the protection levels of the handbook protection procedure.

A current list of the practices in the various categories are given in Table A-1.

TABLE A-1. HEMP PROTECTION DESIGN AND VALIDATION PRACTICES

1.0 ZONE SHIELDING

- 1.1 Building Shields
- 1.2 Equipment Enclosure Shields
- 1.3 Component Shields
- 1.4 Cable Shields
  - 1.4.1 Solid
  - 1.4.2 Flexible
    - 1.4.2.1 Single
    - 1.4.2.2 Double
  - 1.4.3 Conduits
  - 1.4.4 Cable Trays
  - 1.4.5 Cable Ducts
  - 1.4.6 Trenches
- 1.5 Apertures
  - 1.5.1 Doors
  - 1.5.2 Windows
  - 1.5.3 Vents
  - 1.5.4 RF Gaskets
  - 1.5.5 Shafts
  - 1.5.6 Entry Panels

2.0 ZONE PENETRATIONS

- 2.1 Cable Burial
- 2.2 Ground Plane
- 2.3 Fiber Optics
- 2.4 Filters
- 2.5 Surge Arrestors
  - 2.5.1 Gas Tubes
  - 2.5.2 Semiconductors
  - 2.5.3 Hybrids
- 2.6 Balanced Signaling
- 2.7 Cable Clustering
- 2.8 Physical Isolation
- 2.9 Loop and Length Minimization
- 2.10 Circumferential Termination
- 2.11 Non-Electrical Treatment
- 2.12 Protection Device Installation
- 2.13 Receiver Front Ends

3.0 ZONE INTRINSIC HARDNESS

- 3.1 High Level Circuits
- 3.2 U.P.S.
- 3.3 Read Only Memories (ROM's)

4.0 ZONE GROUNDING

- 4.1 Outside
  - 4.1.1 Counter-poise
  - 4.1.2 Ring
- 4.2 Inside
  - 4.2.1 Regional

5.0 PROTECTION VALIDATION

- 5.1 Visual Inspection
- 5.2 Injection Test
  - 5.2.1 C.W.
  - 5.2.2 Pulse
- 5.3 Shielding Effectiveness Test
- 5.4 Free Field Test
- 5.5 Qualification by Test
- 5.6 Qualification by Analysis
- 5.7 Transfer Impedance Test
- 5.8 Earth Resistivity Test
- 5.9 Protection Component Screening
- 5.10 Attenuation and Response Test

APPENDIX B - EQUIPMENT RESPONSE

B.1 INTRODUCTION

The subject of this appendix is the response of equipment and component parts to HEMP fields and induced transients. The appendix is provided as a resource for specification of allowable equipment response in 3.2 of Part 1 and to act as a reference base for the protection validation practice of analysis.

The appendix discusses upset and damage of component parts as well as providing generic data on upset and damage thresholds of equipment. Additionally it will cover equipment response analysis.

HEMP produces two distinct kinds of equipment and component part response: upset and damage. Upset is a non-permanent alteration of the equipment or component part operation state which is self correcting or reversible by automatic or manual means. Damage is an unacceptable permanent change in one or more of the equipment or component parts characteristics.

The spectrum of thresholds for some component parts are shown in Figure B-1. From the diagram it is apparent that semiconductors are very susceptible to HEMP and thus often require protection.

B.2 UPSET (Ref. B.1, B.2)

Transient upset, whose threshold is at least an order of magnitude below the damage threshold, occurs when an induced HEMP transient exceeds the operational signal level and has a time scale that falls within the circuits time response. Figure B-2 shows some examples of upset. Figure B-2(a) illustrates a flip-flop changing state due to an HEMP transient on the trigger input. Figure B-2(b) illustrates a NAND gate changing its output logic level temporarily from a HEMP transient on the power supply line. Figure B-2(c) shows an amplifier being driven into saturation by a HEMP transient super-imposed on its signal input. Upset thresholds for several logic families are shown in Figure B-3.

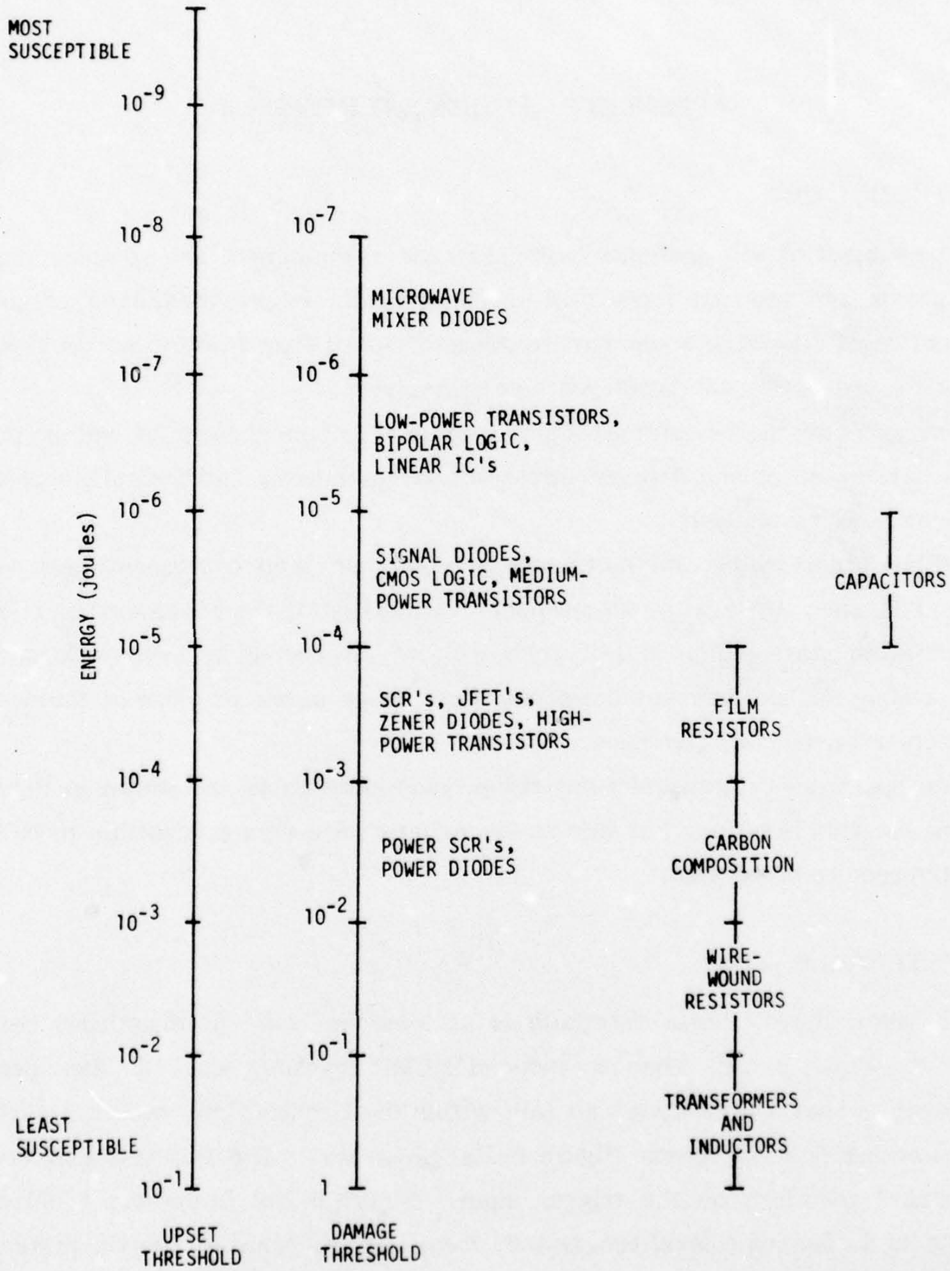
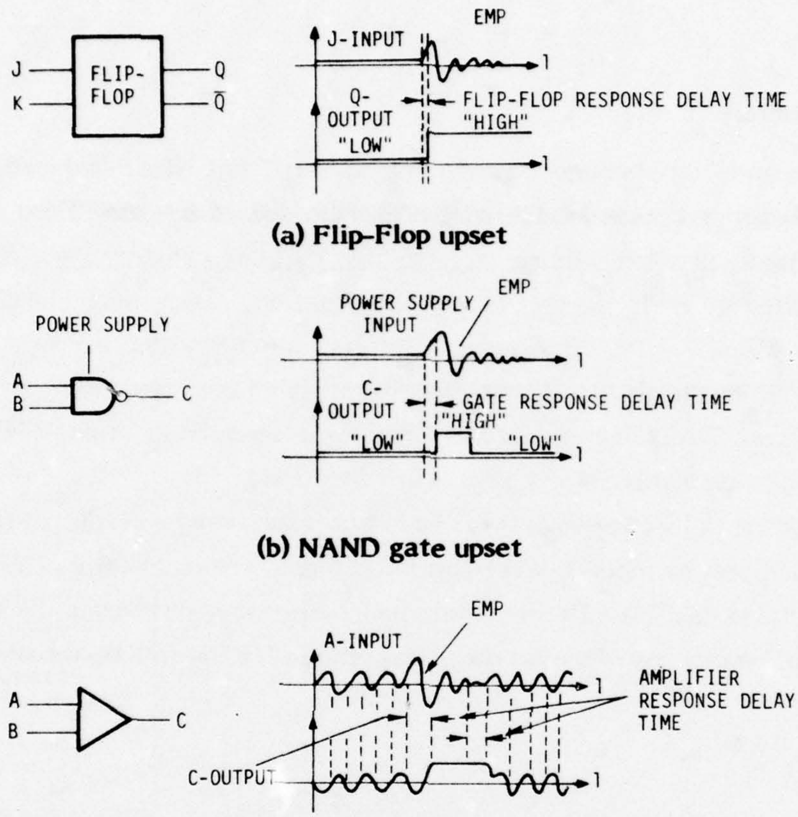


Figure B-1. Spectrum of response thresholds for component parts



(a) Flip-Flop upset

(b) NAND gate upset

(c) Amplifier upset

Figure B-2. Examples of transient upset

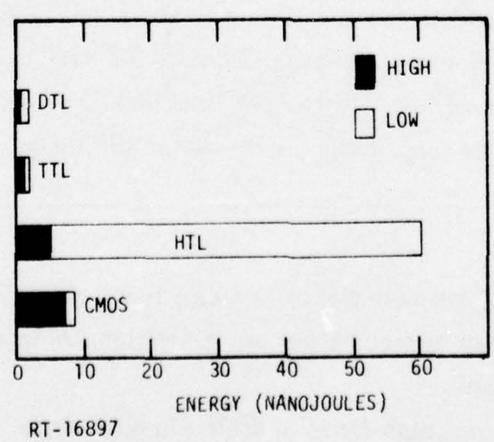


Figure B-3. Upset thresholds for four different logic families

B.3 DAMAGE

B.3.1 Semiconductors

Most semiconductor damage mechanisms arising from HEMP-induced transients are energy-dependent processes, since they are often caused by some form of thermal failure. The most common failure is localized thermal runaway, which generally produces a resolidified melt channel across the junction, whose equivalent form is a resistive short circuit. For integrated circuits, metallization burnout is also a prominent failure mechanism. Forward-stressed junctions typically have damage thresholds which are 3 to 10 times higher than reverse-stressed junctions due to the low voltage and impedance levels present in forward conduction.

Semiconductor failure thresholds for transient pulses can be predicted from known or measured quantities by models developed for discrete semiconductors (Ref. B.3) and integrated circuits (Ref. B.4). These models, which are based on thermal considerations and experimental results, yield the following expression for the failure-threshold level.

$$E_T = Kt^B \quad ,$$

where E_T is the failure energy required in a time, t, to produce device failure, and K and B are device-dependent constants. For discrete devices, K is usually obtained experimentally and B is zero for pulse widths less than 100 nsec, 0.5 for 100 nsec to 300 μsec, and unity for longer pulses. When test data is unavailable on discretes, K can be obtained from empirical relations given in Reference B.1 and data sheet information. For integrated circuits, K and B are determined experimentally; however, when test data is unavailable, typical values of these coefficients for various classes of integrated circuits are given in Reference B.4. Note that the threshold energy for devices is a statistical quantity and the value normally calculated is the mean value.

B.3.2 Passive Parts

The passive parts most susceptible to damage from HEMP-induced currents are those with very low voltage or power rating and precision components where a small-parameter change is significant.

Resistor failures due to high-level pulsed current arise from energy-induced thermal overstress and voltage breakdown. Resistor failure threshold can be calculated from the resistor parameters and the empirical relation given in Reference B.5.

Exposure of capacitors to transient currents produces a voltage across the capacitor which increases with time, as $1/c \int I\, dt$. For nonelectrolytic capacitors, this voltage behavior continues until the capacitors dielectric breakdown level is reached, which is typically ten times the dc voltage rating. For electrolytic capacitors, the voltage relationship holds until the zener level of the dielectric is reached, at which time damage can then occur. The damage level for electrolytic capacitors in the positive direction is 3 to 10 times their dc voltage rating, and for the negative direction it is 1/2 their positive failure voltage (Ref. B.6).

Transformer and coil damage due to HEMP-induced currents occurs from electric breakdown of the insulation. The pulse-breakdown voltage is typically 5500 volts for power supply transformers and 2750 volts for small signal transformers (Ref. B.11).

B.4 GENERIC THRESHOLD OF EQUIPMENT

Localization of response to specific circuits or component parts is often not possible for complex equipment obtaining identical or similar circuits. Consequently when one is considering equipment response it is often more realistic to deal with the thresholds at the equipment level as opposed to that at the circuit or part level. The only difficulty in using the equipment thresholds approach is that only a limited set of equipment have had their thresholds analyzed or measured. Measured thresholds for some types of DCS equipment are given in Table B-1.

B.5 RESPONSE ANALYSIS

Response analysis of complex systems such as the DCS consists of the following four phases: data collection, susceptibility screening, detailed analysis, and vulnerability classification. These different phases are illustrated by the flow diagram given in Figure B-4.

Data collection involves the acquisition of all technical documentation necessary for performing the analysis. This documentation includes schematics, interconnect diagrams, wire lists, circuit and operational descriptions, circuit types, component part numbers, and pertinent results of site surveys.

Susceptibility screening is accomplished in two steps. First a gross circuit screen is carried out based on the predicted levels of HEMP fields and induced transients within the facility or equipment, the location of circuits, their generic type and the spectrum of component susceptibility. This screening generally eliminates many of the

TABLE B-1. RESPONSE THRESHOLDS (Ref. B.7, B.8)

Equipment	Lead	Upset Level, p-p (A)	Damage Level, p-p (A)	Maximum Stress Level, p-p (A)
Primary frequency supply (PFS-2A)	-24 V	0.4	--	9
A5 channel bank (solid state modem)	-24V	80	--	150
	Input	--	150	150
	Gain	--	75	75
Multiplex				
WELMX-1 (tube)	130 V	0.07	--	1
WELMX-2 (solid-state)	-24 V	0.02	60	60
WEMMX-1 (tube)	130 V	2	--	2
WEMMX-2 (solid-state)	-24 V	--	--	50
Wireline entrance link, 3A (amplifier)	-24 V	1	--	35
100-A protection switch (switching unit)	+24 V	0.2	--	0.9
TM-1 radio	-27 V	--	25	25
L4 cable system				
Trigger A equilizer	-24 V	8	--	110
Protection switch	-24 V	16	--	110
WE TD3 radio	DC power	50	--	--
WE TH3 radio	DC power	60	--	--
Farinon FM 2000 radio	DC power	208	240	--
Lenkurt 778A2 radio	DC power	35	--	--
Collins MW608D radio	DC power	50	--	--

microwave and RF circuits, and circuits containing relays, motors, and other intrinsically protected components. The second screen utilizes the predicted field and transient levels, along with suitable screening criteria to further eliminate circuits that are intrinsically protected due to design, use of component type, or component value.

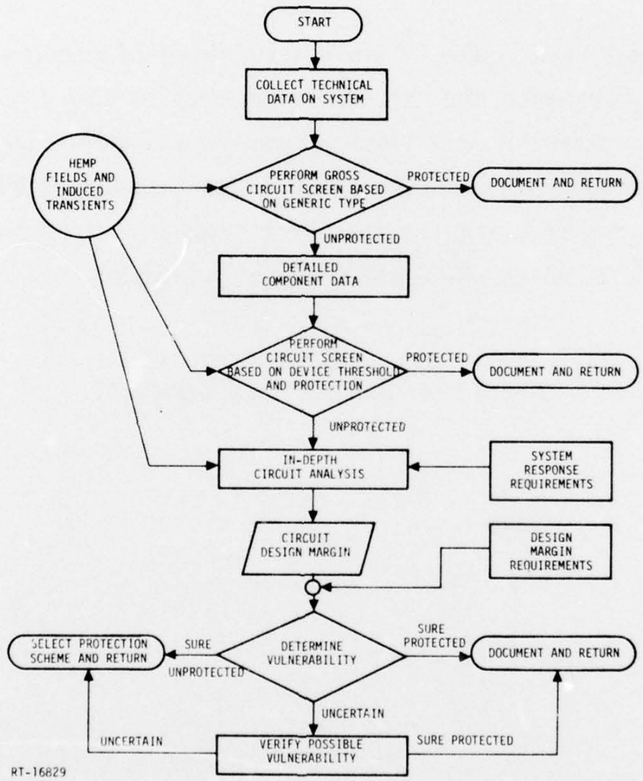


Figure B-4. Flow chart of response analysis

The third phase involves performing in-depth circuit analysis on circuits that were determined to be potentionally unprotected during the screening process. Simple circuits are analyzed by hand using equivalent energy pulse excitation and linear analysis techniques (i.e., loop and driving point impedance analysis). More complex circuits are analyzed by computer using transient analysis programs such as TRAC (Ref. B.9) and SYSCAP (Ref. B.10). Conventional semiconductor models are not completely adequate for response analysis since the high level HEMP transients can

force the semiconductors into abnormal operational modes. Hence the analysis employs conventional semiconductor models altered to allow for junction breakdown. Integrated circuit models are modified by incorporating the simple terminal damage model developed by Jenkins and Durgin (Ref. B.4). The circuit analysis yields the energy (or voltage and current) produced at selected device terminals by the induced HEMP transients. This energy is compared to the device threshold and a design margin is calculated.

The final analysis phases concerns the determination of circuit vulnerability. This is accomplished by comparing the circuit design margin to system design margin requirement and then classifying the results based on a suitable safety margin assessment method. This vulnerability assessment after iteration finally results in the circuits being grouped into sure protected which require no further action and those that are sure unprotected or uncertain which require protection.

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APPENDIX C - PENETRATION AND COUPLING INTO SHIELDED ENCLOSURES

C.1 INTRODUCTION

This appendix concerns the interaction and coupling into shielded enclosures. It discusses the techniques for calculating internal fields and induced currents from apertures, diffused fields, and direct coupling. It is provided to support the section on HEMP zone environments given in 4.4 of Part 1 as well as to act as a resource for protection validation by analysis.

C.2 COUPLING INTERACTION

In analyzing HEMP response of the DCS it is essential to be able to relate the exterior environmental threats to system, subsystem, and circuit responses. The functional relationship between external causes and internal effects is often referred to as a transfer function. The analysis involves determining how the system collects energy from the incident HEMP field. The end product is usually a matrix of internal fields and transient voltages and currents which may flow in circuits and subsystems. This is referred to as a determination of the coupling interactions between the external threat and the system.

Generally there are three different modes of entry of HEMP into enclosures: diffusion through the walls; coupling through apertures such as seams, joints, and windows; and direct penetration via intentional or inadvertent antennas. These different mechanisms are illustrated in Figure C-1 and are discussed in the following sections.

C.3 DIFFUSION (Ref. C.1-C.3)

Diffusion of HEMP fields takes place through imperfectly conducting walls of shielded enclosures. The diffusion is primarily magnetic in nature and is a low pass filtering phenomenon as illustrated by the magnetic shielding effectiveness curve of an ideal enclosure given in Figure C-2. The field that reaches the inner region of a shielded enclosure is thus primarily a low frequency magnetic field. This effect is most

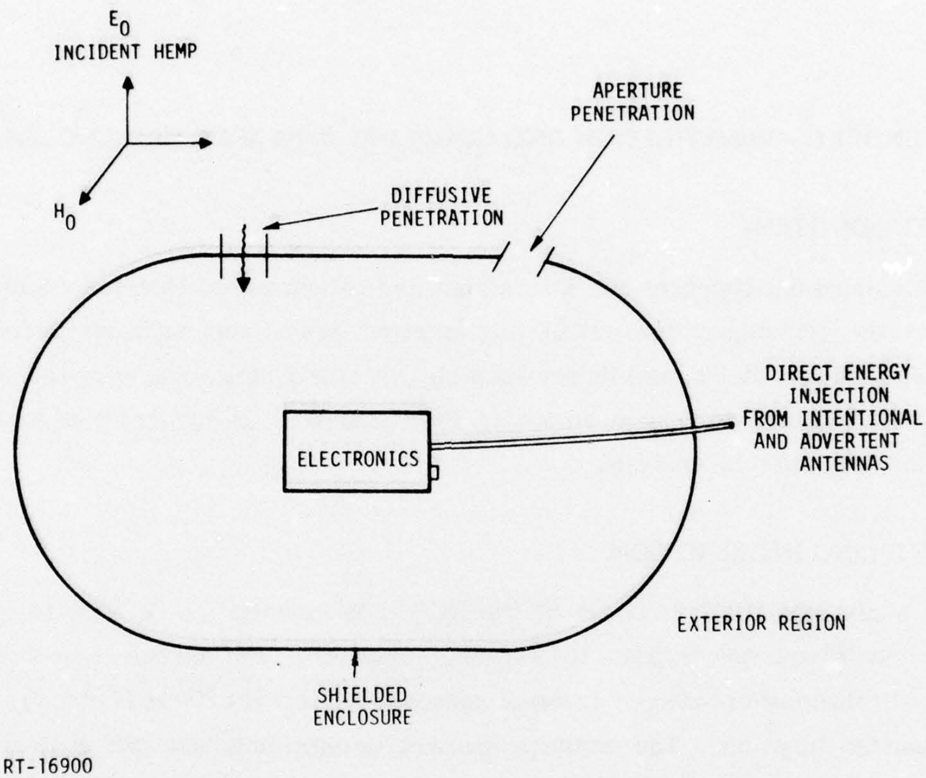

Figure C-1. Three modes of penetration and coupling into shielded enclosures

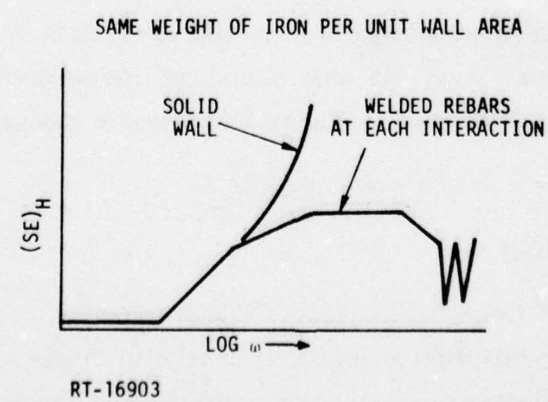

Figure C-2. Magnetic shielding effectiveness of an enclosure with solid walls and an enclosure with rebar (Ref. C.3)

pronounced in an enclosure with solid metal walls, but is also observed to some degree in enclosures with metal rebar or wire mesh reinforcement. The shielding effectiving for an enclosure with rebar is also shown in Figure C-2. The reduced shielding effectiveness at high frequencies for rebar and wire mesh enclosures allow a significant fraction of the incident HEMP environment to penetrate to the electronics within the enclosure.

C.4 APERTURES (Ref. C.4, C.5-C.6)

Apertures and shielding compromises are represented by doors, windows, holes for adjustments and display devices, seams, improperly terminated cable shields, poorly grounded cables, etc. Each aperture provides a leak through which the HEMP field can directly couple into the shielded enclosure. The leakage through an aperture depends on its size, the type of structure containing the aperture, and its location. The aperture responds to both the total magnetic and electric field at the aperture location. The effect of apertures on the magnetic shielding effectiveness of an ideal enclosure is illustrated by Figure C-3.

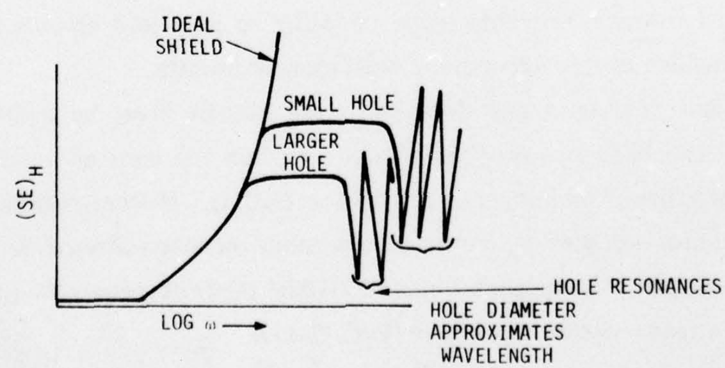

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Figure C-3. Magnetic shielding effectiveness of an ideal enclosure and an enclosure with apertures (Ref. C.3)

C.5 INTENTIONAL AND INADVERTENT ANTENNAS

Intentional antennas are designed to be collectors of electromagnetic energy over specified frequency bands - hence they will respond in some fashion to HEMP. As the incident HEMP field has a broad frequency spectrum as well as a high field strength it is necessary to consider the antenna response both in and out of band. Several techniques are available (Ref. C.7-C.9) for modeling different antennas in determining their response to HEMP. These models, along with the incident field, yield the HEMP energy appearing at the connecting cable and subsequently to the electronics within the enclosure at the other end of the connecting cable.

Inadvertent antennas (Ref. C.2) are electrical, conducting external structures, cables, and pipes that collect HEMP energy and penetrate the enclosure walls thus allowing HEMP energy to enter the enclosure. As a rule, the larger the inadvertent antenna, the more efficient an energy collector it is in producing larger transient levels within the enclosure. Coupling response of inadvertent antennas are generally analyzed by using the transmission line and simple antenna models.

C.6 INTERNAL CURRENTS

HEMP transients on intrazone cables arise from currents induced by aperture and diffused fields and by currents brought in on conductive penetrations. Aperture and diffused fields couple to intrazone cables by EM loop and dipole coupling. A recent statistical study of internal currents using coupling to loop and dipoles (Ref. C.10) has yielded results that are in fair agreement with measurements.

Intrazone cable currents are delived to the circuit level by either hardwire or mutual coupling. The hardwire mechanism occurs when the excited conductor connects by some continuous direct or indirect path to the circuit. Mutual coupling occurs when the excited conductor couples by mutual inductance or capacitance to a cable which connects to the circuit. Note that induced HEMP current generally propagate along conductors via the transmission line mode (Ref. C.11).

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SUMMARY AND RECOMMENDATIONS

The Prototype Design Practice Handbook program represents a 13 month effort to produce a basic structure and topic outline of a HEMP Design Practice Handbook for the design and specification of HEMP protection for DCS facilitiés and equipment. This Extended Outline, which is product of that program, provide the outline and framework for the Design Practice Handbook.

The Extended Outline contains the protection methodology; a corresponding protection procedure; handbook chapters, sections and subsections with some content development of much of the outline; and rationale and references where appropriate.

In its present form the Extended Outline of course is not a complete handbook and thus cannot be utilized as a tool in protecting the DCS.

The voids identified during the handbook effort are given in Table I. Most of the voids listed are not major technological ommissions. Rather the voids principally exist because information was unavailable in the form required for its use or time constraints precluded its acquisition. A major program to fill in the voids is not recommended as those that are critical to the handbook development can be included as part of the handbook development program.

IRT recommends an immediate effort be initiated to complete the development of a first generation handbook so that DCA and its contractors can have an effective and systematic means of providing HEMP protection for the DCS. A comprehensive program is suggested for development of the first generation handbook involving two men for eighteen months. The important points of this program are summarized in Table II, section A. This comprehensive effort would yield a complete handbook based on currently available data as well as data developed to fill in critical voids. Where data is required and unobtainable within the program constraints, the method for generating the data would be included. A major element of the program involves interaction with prospective users by visiting their facilities and instructing them on the handbook, and allowing them to critique and validate the handbook by using it in dealing with their HEMP protction problems. This program would include complete development of the protection quality assurance aspect of the handbook as well.

TABLE I. LIST OF VOIDS

1. The overall level of shielding required for HEMP protection of:

   Facilities
   Enclosures
   Equipment Components

2. Relation of HEMP S.E. to C.W. Measurements
3. Criteria For Penetration Coupling Reduction and Aperture Treatment
4. Tables of induced currents for different types of antennas.
5. Bounds on coupling reduction requirements for receiver front-ends
6. Tables of worst-case zone environments for different S.E. levels and number of nested shields
7. Reasonable equipment response criteria
8. Reasonable maximum equipment component specification for:

   Fields
   Interface levels

9. Generic equipment thresholds
10. Tabulation, correlation, and interpretation of the results of all threat level tests of DCS facilities
11. Protection design margins and how they should be allocated
12. Tabular and graphical data of factors that affects allocations and design practice selection
13. DCS documents covering protection quality assurance
14. Military specifications concerning HEMP protection requirements
15. Official documents for Design Reviews, First Article Inspections, Validation, and Acceptance Tests which address HEMP protection
16. Design and Validation Practices and supporting data
17. Development of Quality Assurance aspects of the handbook
18. Complete development of the handbook.

If funding limitation prevents the more desired comprehensive program from being carried out, a suggested alternative is a moderate program for handbook development. The moderate development program involves a one man level effort for twelve months. This program would yield a bear minimum handbook that would be complete enough to use as a protection tool in the early phases of facility and equipment development. A summary of the major points of the program are given in Table II, section B.

It would utilize currently available data along with that developed to fill in critical voids. Methods for generating required data which is unavailable would also be included. The interaction aspect of this program would involve critique of the handbook by various members of the technical community. Only a small effort would be directed toward development of the protection quality assurance chapters.

Both efforts would require the design and validation practices hence a concurrent program of development of the practices is mandatory so they will be available for inclusion in the first generation handbook.

TABLE II. FUTURE PROGRAM RECOMMENDATIONS

A. COMPREHENSIVE PROGRAM:

1. Two-man level eighteen month effort
2. Uses data that is currently available
3. Uses data developed to fill critical voids
4. Will contain methods for generating required data that is unavailable
5. Contain a minimum essential set of data and design practices (if available)
6. Includes complete development of protection assurance area
7. Handbook critiqued and validated by interaction with perspective users
8. Complete in the sense that it can be used.

B. MODERATE PROGRAM

1. One-man level twelve month effort
2. Uses data that is currently available
3. Uses data developed to fill critical voids
4. Will contain methods for generating required data that is unavailable
5. Contains a minimum essential set of data and design practices (if unavailable)
6. Some development of the protection assurance area
7. Handbook critiques by technical community
8. Complete enough to be used in the early phases of equipment and facility development.